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U. S. ARMY ELECTRONICS MATERIEL AGENCY.

PRODUCTION ENGINEERING MEASURE

DA - 36 - 039 - SC - 86727

SILICON PLANAR EPITAXIAL TRANSISTOR

TYPE 2N2193

SILICON GROWN DIFFUSED TRANSISTOR

TYPE 2N336

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U. S. ARMY ELECTRONICS MATERIEL AGENCY

PRODUCTION ENGINEERING MEASURE

DA - 36 - 039 - SC - 86727

SILICON PLANAR EPITAXIAL TRANSISTOR

TYPE 2N2193

THIRD QUARTERLY REPORT

31 OCTOBER 1962
31 JANUARY 1963

(S. O. Johnson)

PROJECT MANAGER

TABLE OF CONTENTS

I. AREA OF WORK - IMPROVED KPR RESOLUTION (C. LOGAN)

1 A. Work Item - Improved light collimation during KPR exposure.

B. Abstract - A highly collimated, mercury arc light source of departmental design was built, and made an integral part of our present KPR-alignment-exposure gear. It has been debugged and is presently being used for high resolution exposures.

C. Purpose - The significance of a collimated light source during KPR exposure is to minimize light scattering, refraction and wafer-mask contact effects during the exposure of the KPR oxide masking pattern, thus minimizing pattern resolution degradation.

D. Narrative and Data

The mercury arc light source, which consists basically of a series of collimating lenses and a front surface mirror for reflecting the ultra-violet light meets all requirements for high resolution exposures.

Evaluation relative to light collimation was made, using high resolution KPR masks containing 0.5 mil. opaque patterns. Exposures were made onto KPR coated wafers, through the masks, and the resultant KPR patterns were examined at high magnification (300 - 400 X), to establish relative resolutions (smoothness of pattern edge). Pattern resolutions in the order of 1 - 2 microns could be obtained. This matches the opaque pattern edge resolution inherent in the KPR masks, indicating that the maximum effective light collimation has been obtained.

E. Conclusions

High resolution exposures for the KPR masking of window etching processes can be obtained using this light source design. It is presently in use on our production line and standard material flow is being scheduled through this gear.

F. Program for next Quarter

This work item is completed.

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2 A. Work Item - Mask-Wafer "Contact" Exposure Effects.

This work item has been completed.

3 A. Work Item - High Resolution Masks.

This work item has been completed.

II. AREA OF WORK - CONTACT EVAPORATION AND ALLOYING (C. LOGAN)

1 A. Work Item - Improved Substrate Heater Design.

B. Abstract - The infrared substrate heater design was finalized, fabricated and installed in all the vapor deposition systems used for contact processing.

C. Purpose - Consistent and uniform aluminum contact surfaces and alloying necessitates controlled deposition and alloy temperature cycles as exhibited by the substrate heater. The particular heater designs mentioned should minimize gradient effects characteristic of large area heaters.

D. Narrative and Data

The infrared heater design, as described in the last quarterly report, was installed in all vapor deposition systems. All standard production line material is currently being processed for contacts, using this substrate heater design.

The virtual elimination of over- or under-alloy extremes in the contact process, as determined by in-process measurements such as high energy ultrasonic vibration and chemical removal of contacts for the microscopic examination of aluminum-silicon interface, has resulted from the incorporation of this new heater design. Such extremes were a common occurrence in the old resistance heated substrate holder, occasionally occurring within a single run.

Work is continuing on analytical techniques which can be used for defining the quality of the contact process.

E. Conclusions

The new infrared heater design has effected a significant improvement in the reproducibility and uniformity of the contact process.

F. Program for next Quarter

Work during the next quarter will consist of assessing which of the available analytical techniques for contact evaluation will be adopted for process monitoring.

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2 A. Work Item - Temperature Control Improvements.

This work item has been completed.

3 A. Work Item - Regulated Leak Consideration.

This work has been pre-empted by the vacuum deposition process (See 4A).

4 A. Work Item - Vacuum Deposition Process.

B. Abstract - The elevated substrate temperature deposition process has become standard procedure for contact processing.

C. Purpose - To develop a constant process which would minimize the critical nature of TCB, Thermo Compression Bonding, and promote reproducibility of alloy regions having negligible effect on the electrical parameters.

D. Narrative and Data

Elevated temperature depositions, where applicable, have definite advantages over cold or low temperature depositions (as was discussed in the last quarterly report). Since the adoption of this process these advantages are being realized with our standard production material.

Bondability has improved and stabilized, resulting in a more reliable device, as measured by the ease of lead attachment, drop testing and the incidence of opens. More reproducible and uniform alloying has been obtained, as measured by the "m process" measurements discussed in II. 1. D.

E. Conclusions

All indications are that the elevated temperature depositions are contributing to improved reproducibility of the contact process and improved lead attachment.

F. Program for next Quarter

Work during the next quarter will consist of assessing which of the available analytical techniques will be adopted for process monitoring.

III. AREA OF WORK - COLLECTOR ETCHING (C. LOGAN)

1 A. Work Item - Surface Masking.

This work item has been completed.

IV. AREA OF WORK - BORON DIFFUSION (A. R. DI PIETRO)

1 A. **Work Item** - Replace Present B_2O_3 Solid Source Process by a BCl_3 Gaseous Source Process.

B. **Abstract** - Process measurements of sheet resistivities and penetrations from run to run have shown that, although exceptional uniformity within a single diffusion run is possible in the BCl_3 process, the run-to-run reproducibility which is necessary for a manufacturing operation is far less than that which can be obtained with the B_2O_3 process. Accordingly, we are retaining the current B_2O_3 process as the best available boron diffusion process.

C. **Purpose** - The goal of the work during this quarter was to establish and optimize the operating procedure for a BCl_3 diffusion process, in order to attain a satisfactory degree of run-to-run reproducibility.

D. **Narrative and Data**

Three hundred runs have been made with the BCl_3 process in order to determine that set of operational conditions which would achieve the maximum reproducibility of results in a day-to-day manufacturing operation. Process control parameters of temperature, carrier gas composition, BCl_3 concentration and oxide thickness have been varied over wide ranges in order to outline the regions of best control.

Uniformity of boron deposition across a wafer and from wafer to wafer is usually exceptional, with extremes in one run often falling within ± 5% of the median. However, continued performance to a fixed target is poor, even under the optimum process conditions. Approximately 20% of the runs carried out with BCl_3 fell within a usable range of sheet resistivity and penetration. This is a considerably less controllable process than our present B_2O_3 method. Although BCl_3 process improvements are still under investigation, especially for high boron concentration applications where the requisite run-to-run reproducibility seems to be easier to obtain, we have decided to use our present B_2O_3 process for the manufacturing of 2N2193 devices.

E. **Conclusions**

A boron diffusion process designed around the use of gaseous boron trichloride as the source material will not afford any improvement in process reproducibility at its present state of development. The BCl_3 method falls far short of matching the run-to-run performance of our present solid B_2O_3 process.

F. **Program for next Quarter**

Work on this item has been terminated due to the facts discussed above. The applied manpower has exceeded the estimated effort on this work item by more than 5%.

V. AREA OF WORK - PHOSPHORUS DIFFUSION (J. F. WHOLEY)

1 A. Work Item - Improved Source Heater for Phosphorus Diffusion.

B. Abstract - Control of the phosphorus diffusion process has been improved by the incorporation of the infrared source heater.

C. Purpose - The objectives of this work item are to:

a. determine the reproducibility of heat-up time from the instant the P_2O_5 is loaded until the desired temperature level is reached.

b. determine the range of temperature fluctuation from this point until the end of the run.

D. Narrative and Data

Heat-up time and temperature fluctuations in the newly-designed P_2O_5 source zone infrared heater have been determined on a number of runs. The heat-up time, i.e., the time elapsed from the insertion of the loaded P_2O_5 boat to attainment of the operating temperature, is typically one minute. This stands in sharp contrast with the old, resistance-heated design, which required approximately six minutes, depending on the experience of the process operator.

Temperature fluctuations during the course of the run are presently $\pm$ 1°C., as contrasted with $\pm$ 10°C. with the old heater design.

E. Conclusions

The newly-designed P_2O_5 source heater will be adequate to supply a significant margin of improvement in the reproducibility and uniformity of the phosphorus process.

F. Program for next Quarter

This work item is completed.

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2 A. Work Item - Improved Technique of Loading Phosphorus Source Boats.

B. Abstract - Individually sealed plastic ampoules, prepared in a nitrogen ambient dry box and containing preweighed quantities of P_2O_5, were obtained and have been used in more than thirty diffusion runs. An improvement has occurred in run-to-run control of emitter doping, as indicated by a significant decrease in the variability of phosphorus sheet resistivity.

C. Purpose - Improvement in the technique of loading the phosphorus source boats to minimize exposure to room air humidity and to achieve uniform effective P_2O_5 source surface area will improve the uniformity of phosphorus concentration.

D. Narrative and Data

A sensitive area in the reproducibility of the phosphorus process has been the inability to control the water content of the P_2O_5 starting material. This is due to the time required to charge the very hygroscopic P_2O_5 into the source boat. In order to minimize this exposure to room air, a volumetric technique is used to load the source boats. This technique does not, however, give a reproducible quantity of P_2O_5, due to differences in the bulk density of P_2O_5, which introduces another source of variability.

In order to overcome these deficiencies in the standard phosphorus process, we have developed, with the help of commercial interests, a sealed, inert, plastic ampoule,* which is charged with an accurately weighed quantity of P_2O_5 in an inert atmosphere dry box. These ampoules are delivered in individual plastic envelopes which contain an indicator desiccant and are sealed with a plastic tie. These packages are kept sealed until they are ready for use, at which time they are opened and charged into the source boat. It was not deemed necessary to provide a dry box for the loading operation, since the P_2O_5 is exposed to the room atmosphere for less than five seconds.

Both the former loading method and the ampoule method gave average sheet resistivities essentially on the desired target for the 2N2193 structure, when compared over a span of sixty diffusion runs, approximately half by each method. However, the values ranged ± 12% from the median when using the older method, as compared to ± 8% from the median when using the ampoules. Phosphorus glass thickness was checked on selected runs which showed the maximum deviation from the sheet resistivity target. Thickness variations occurring in the runs using the older method were nearly twice those of the ampoule runs, as estimated from the number of dark lines observed in thallium light, using an angle lapping technique.

E. Conclusions

A significant improvement has been obtained in the run-to-run reproducibility of the phosphorus diffusion process by the use of pre-weighed, highly desiccated P_2O_5 ampoules amenable to extremely rapid loading into the source boat.

F. Program for next Quarter

This work item is completed.

* The ampoule is a cylinder ½" in diameter and 1" long. The cap material is polyethylene; the vial material is polystyrene.

VI. AREA OF WORK - COLLECTOR CONTACT TO THE HEADER (R.H. LANZL, J.L. DURSO, J. RICHARDSON)

1.A Work Item - Reduction in Size of Preform.

The basic work item is that of providing rapid, accurate, reproducible attachments of preforms to headers prior to pellet mount, and further to optimize the entire pellet mount process.

B. Abstract - Work progress primarily involved the debugging of equipment. Problems more severe than were anticipated in preform placement accuracy, which includes equipment feeding mechanism and header locating, have slowed completion of this work item. Additional changes were proposed which should eventually solve the problem. The actual equipment modifications have yet to be completed.

It was decided that further work to eliminate preforms and introduce resistance-heating pellet mount techniques will not be continued at present. Too many inconsistencies and additional process variables exist to justify further work immediately.

C. Purpose - The goal during this work period was to complete, as nearly as possible, the tooling for, and debugging of, automatic preform mount equipment and, as a corollary, to increase pellet mount rates.

D. Narrative and Data - Work was completed on more accurate header locating tooling for the existing preform mount machine. Further, design changes were made more accurately to feed preform ribbon prior to cut-off and weld. To increase further the accuracy of the equipment "system", it was found necessary to re-machine basic equipment drive and index components. Increased ribbon feed accuracy is to be obtained by replacing matching feed "slots" with a fabricated "tunnel" assembly.

Equipment was provided which gives up to 60% increases in "conventional" preform mount rates.

E. Conclusions - Several weeks will still be required before the equipment system and its tooling can operate at the degree of accuracy required.

F. Program for next Quarter - Continue the debugging of preform mounting equipment for satisfactory performance.

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2 A. Work Item - Reduction of the Corroding Species by Improving Cleaning and Tighter Inspection of Purchased Material (F.K. GLASBRENNER, R.J. KOBLER)

B. Abstract - During this period our investigation continued on "as received" material prior to line experiment.

C. Purpose - To obtain more detailed and complete data regarding the control of incoming material prior to line experiments designed to summarize the effect upon device performance.

D. Narrative and Data - a. Preform Cleaning - as Detected by Infrared Analysis.

Surface contamination on "as received" material previously reported as 20 ppm was substantially reduced, to 3 - 9 ppm, after line cleaning.

A second analysis was performed on some "as received" material. It was found to be free from infrared active material.

b. Header - Analysis of Gold Plating Quality.

1. Thickness control and uniformity by metallographic techniques are as follows:

Vendor	Average Thickness (Micro-Inches)	Maximum/Minimum Thickness (Micro-Inches)
A	210	250 / 180
B	151	214 / 115

The specification calls for 100 micro-inch minimum gold plating, which both vendors easily comply with. However, uniformity of plating is very difficult to control due to header fabrication and is not felt to be of critical importance, since we use a preform which tends to minimize the effect of an irregularly plated surface.

2. Plating purity by chemical and spectrographic techniques:

Two different chemical methods for the removal of gold from the header have been unsuccessful. For the first sample, a 2% sodium cyanide solution was used; for the second sample, an aqua regia solution was used. This approach, therefore, will be tabled and information from vendors will be obtained to verify the purity of the gold.

E. Conclusions - To date, information on "as received" materials (cap, preform, header) is felt to be complete, except as noted, to the point that line experiments comparing "as received" with cleaned material can be run to determine the effect upon the corroding species.

F. Program for next Quarter - Line experiments will be run and the effects noted of thermal cycling upon gold plating surface and adhesion to base metal, and comparison made between "as received" and "cleaned" parts.

VII. AREA OF WORK - INTERCONNECTIONS.

1 A. Work Item - Improve Bonding Process (LANZL, DURSO, SMITH, KOBLER)

B. Abstract - 1. Work was directed toward determining the relationship between bond strength and the following:
Wedge design, bonding wire characteristics, high temperature aging and pellet aluminum surface condition.

2. During this period parts were processed on the line, using wire from Vendor B, and a study of wire specifications was initiated

C. Purpose - 1. To obtain an optimum bonding process using the new wedge design and several types of bonding wire having a range of known physical characteristics.

2. To determine the optimum wire specifications and processing to obtain strong bonds and second source for wire.

D. Narrative and Data 1. Three experiments, comprising a total of 600 units, were performed to evaluate the variations of bond strength with respect to various pellet surface conditions, bonding wire characteristics, wedge design and high temperature aging conditions.

Two experiments were designed to detect variations in bond strength as a function of detectable visual appearance in the pellet aluminum surface condition. Six equally weighed categories of pellet surface types were selected, which included any maximum process variations which could exist in pellet fabrication. These groups were fabricated using one combination of a new wedge design and a new type of bonding wire, along with the "standard" process as the control. All units were subjected to a step-stress centrifuge test consisting of 35 kG for one minute, 35 kG for 5 minutes, 35 kG for 10 minutes and 50 kG for one minute in the Y_1 plane only.

The net results showed a significantly higher bond strength for combination of new wedge and wire type as compared with the "standard" process, for all categories of pellet surface type. There was no significant difference in bond strength among the various pellet categories for either the new wedge and wire type combination or the control process. Based on these results, it was determined that variations in visual appearance of the pellet surface condition could be disregarded in the evaluation of the rest of wedge designs and bonding wire types.

The third experiment was designed with a matrix to combine wedge design, physical characteristics of bonding wire and 300°C. aging. The following data describes the matrix, and the results are tabulated in Figure 1 on the following page.

Figure 1

	Source Material Lot # 253				
	New Wedge Design		"Standard" wedge, 2 bonds		
	300°C. Age*	No Aging	300°C. Age*	No Aging	
Number of Units in Sample	26	27	26	28	New wire
Combination Code	A	B	C	D	Type 13%
No. Failing 35 kG for 1 min.	1	2	1	16	Elong -
No. Failing 50 kG for 1 min.	0	11	4	9	ation.
Number of Units in Sample	25	24	25	23	
Combination Code	E	F	G	H	Standard
No. Failing 35 kG for 1 min.	0	3	1	13	Wire
No. Failing 50 kG for 1 min.	2	14	2	7	

* = Aging time, 72 hours.

The results from this data show differences in bond strength to be more predominant between the aged and non-aged categories. It appears that a significant improvement can be obtained using the new wedge design as compared with the "standard" wedge. Since only minor variations exist among the new wedge designs, it will be necessary to subject units to stress levels higher than 50 kG to determine the optimum design for maximum bond strength. It also appears that an optimum age time may exist, and future experiments should be designed with a matrix which includes variations in age time to determine bond strength.

Comparing the above results with those exhibited in the second quarterly report (Fig. 2, page 26), the total failures for 20 and 30 kG stress levels in the Y_1 plane numbered 5 in a sample of 50, whereas the total failures in combinations A and E in Figure 1 above for 35 and 50 kG numbered 3 in a sample of 51. This comparison demonstrates a significant improvement in failure rate at a 66% higher stress level.

2. Wire Evaluation.

a. Re-annealing.

A review of this area has revealed that spooling gold wire on aluminum spool and re-annealing results in inconsistent bonding. An immediate change of spool material to stainless steel was initiated and is in use on the line at present. The change of spool material, however, may have affected the re-annealing cycle, and a higher temperature cycle is being investigated. Wire in hard temper has been received in an attempt to reduce the effect of cold working during the re-coiling of the wire prior to annealing.

b. Elongation and Breaking Load Measurement.

Elongation measurement techniques are not standardized

throughout the wire industry, but gage length is generally agreed to be 10"; drawings were changed accordingly. The rate of pull is not critical in this area and therefore correlation with the vendors is improving.

Breaking load (tensile strength) correlation was found to be closely related to rate of pull, and techniques in handling wire. The drawings now specify the rate of pull for vendor reference.

c. Surface Contamination.

The determination of surface contamination by infrared analysis on our small wire requires a large quantity of wire in order to obtain accurate values. Samples after cleaning will be taken, to compare with previously reported 23 ± 10 ppm "as received" value.

d. Second Source of Wire Supply (Vendor B).

Vendor B has supplied various tempered wire, ready to be used directly on the production line. The following pull forces were obtained by static loading (gms) of wire perpendicular to the axis and centered between the pellet and post bonds.

Figure 2

Vendor	Elongation %	Average Bond Strength After		Opens Line Drop Test %	Opens After 20 kG Centrifuge %
		TCB (gms)	Process Bake (gms)		
B	1	10	-	4.5	5
B	9	14	9	2.3	0
B	13	8	5	1.2	0
B	16	9	6	1.6	2.7

Thus, our results indicate a decrease in bond strength due to the bake process. However, our test program is not complete (Drop Shock, Temperature Life Test and higher stress centrifuge tests are to follow) and the effect on performance is not predictable based on pull test results. The data does tend to indicate that the 1% elongation range is undesirable and causes the failure rate to be out of proportion to all other material tested.

E. Conclusions

1. A significant improvement in bond strength failure rate at a 66% higher stress level has been obtained during this work period.

2. Due to changes in the type of spool used, the testing of wire (and corresponding changes in the drawing), better control of the bonding process is well under way. The use of material supplied directly from the vendors should decrease the chances

of using improper wire due to additional inspection of the wire.

The elongation range of 9 - 13% appears to be presenting itself as the best wire type from Vendor B.

F. Program for next Quarter

1. Continue the evaluation of new wedge designs and types of bonding wire to obtain an optimum process for maximum bond strength.

2. Complete the evaluation of surface contamination by infrared analysis of wire after cleaning

3. Complete the tests on the initial experimental samples of wire from Vendor B, and introduce the optimum wire type into the production line.

VIII. AREA OF WORK - RELIABILITY MEASUREMENT (T. E. JACOBS)

1 A. Work Item - Completion of Phase I Series of Step Stresses; Proposed Revision of Phase II Tests.

B. Abstract - All of the Phase I step-stresses have either been completed or discontinued. Complete results are shown in Figures 3 and 4.

The step-stress technique has been effective principally in detecting inversion failures (temperature step-stress plus V_{CB} = 45 V.) and mechanical weaknesses (centrifuge step-stress). In Phase II, therefore, only these step stresses, plus the temperature alone step-stress, will be retained; and the report will discuss a possible substitute plan which:

a. attempts to determine the effectiveness of one or two screens.

b. obtains an estimate of the relationship between failure rate and stress. This would assist in determining sample sizes and conditions for the fixed stress tests which are used for the estimation of that particular stress which would give a failure rate of 0.001%.

C. Purpose - Phase II as proposed will:

a. determine the effectiveness of one or two screening procedures

b. provide a measure of product improvement (by use of the two step-stress tests which proved to be effective during Phase I).

c. obtain an estimate of failure rate versus stress, which will assist in determining the sample size for the final fixed stress reliability estimation tests.

D. Narrative and Data - Figures 3 and 4 present completed data for the Phase I series of step-stresses. This data and the Failure Analysis of Rejects presented in the second quarterly report (pp 27 - 31) indicate that the two principal reasons for device degradation as shown by this series of step-stresses are:

a. inversion layers (these failures appear principally on voltage plus temperature step-stress).

b. mechanical weakness (appearing principally on centrifuge).

In Phase II, these two step-stresses will be repeated and a comparison of results - Phase I versus Phase II - will enable a measure of process improvement to be made over the Contract period.

In addition to retaining the voltage plus temperature and centrifuge step-stresses during Phase II, temperature alone step-stress will be repeated, since there is some indication that high temperature stresses reveal the quality of lead bonding and alloying.

FIGURE 3

TABLE SHOWING CUMULATIVE FAILURES

STRESS	HOURS /STEP	NO. OF UNITS	TEMPERATURE IN °C. 300	320	340	360	380
a. TEMPERATURE STEP STRESS	1	20	0	0	0	0	20
	4	20	0	0	1	1	20
	20	20	0	0	0	0	20
	92	20	0	0	0	1	20
	192	20					

STRESS	HOURS /STEP	NO. OF UNITS	TEMPERATURE IN °C. 200	220	240	260	270	280	290	300	310	320
b. TEMPERATURE STEP STRESS PLUS V_{CB} = 45 V.	1	20	0	0	0	0	0	0	0	0	0	0
	4	20	0	0	0	0	1	1	1	1	1/19	1/18
	20	20	0	0	1	1	1	1	1	1/19	2/19	3/19
	92	20	0	0	0	0	1	6	6	6		
	192	20	1	1	2	3	4	7	8			

STRESS	HOURS /STEP	NO. OF UNITS	POWER IN WATTS 1.0	1.25	1.5	1.7	1.8	1.9	2.0	2.1	2.2	2.3
c. POWER STEP AT V_{CB} = 20 V.	1	20	0	0	0	0	X	X	0			
	4	20	0	0	0	0	0	0	0			
	20	20	0	0	1	1	1	1	1			
	92	20	0	1	2	2	2	2	3			

X = These stresses were missed.

STRESS	HOURS /STEP	NO. OF UNITS	POWER IN WATTS 1.0	1.25	1.5	1.7	1.8	1.9	2.0
d. POWER STEP AT I_C = 0.5 AMP.	1	20	0	0	0	9	10	20	
	4	20	0	0	0	0	0	10	17
	20	20	0	0	17/19	19/19			
	92	20	0	0	20				

STRESS	HOURS /STEP	NO. OF UNITS	POWER IN WATTS 0.5	0.75	1.0	1.25	1.5	1.7	1.8	1.9	2.0
e. POWER STEP AT I_C = 0.25 AMP. 5 MIN. ON, 5 MIN. OFF CYCLE.	1	20	0	0	0	0	0	1	1	2	13
	4	20	0	0	0	0	0	0	0/19	13/19	17/19
	20	20	0	0	0	0	0	2	4	7	18
	92	20	0	0	0	2					

STRESS	HOURS /STEP	NO. OF UNITS	TEMPERATURE IN °C. 50	100	150	200	225	250	275	300
f. TEMPERATURE STEP WITH V_{CB} IN AVALANCHE AT 2 MA.	20	20	1	1	3	9	11	13	15	16

FIGURE 4

TABLE SHOWING CUMULATIVE FAILURES

WORK ITEM & SAMPLE	PLAN		CUMULATIVE FAILURES
a. THERMAL SHOCK/ HUMIDITY 50 UNITS.	10 CYCLES 100°C. WATER TO 0°C. WATER, THEN HUMIDITY (PER MIL-S-19500B, PARA. 40.G, THEN		0
	10 CYCLES 300°C. MOLTEN SOLDER TO -65°C. TOLUENE AND DRY ICE, FOLLOWED BY HUMIDITY PER MIL-S-19500B, PARA. 40.G.		1
b. CONSTANT ACCELER-ATION	20,000 G.	Z_1	1
		X_1	2
		Y_1	4
		Y_2	6
	THEN		
50 UNITS	30,000 G	Z_1	8
		X_1	8
		Y_1	11
		Y_2	15
c. MECHANICAL SHOCK	1,500 G; 4 ORIENTATIONS; 5 BLOWS PER ORIENTATION.		0
	THEN		
50 UNITS	3,000 G; 4 ORIENTATIONS; 5 BLOWS PER ORIENTATION		1
d. VIBRATION FATIGUE	20 G; 100 CPS; 3 ORIENTATIONS, 32 HOURS PER ORIENTATION		0
	THEN		
50 UNITS	50 G; SWEEP 100 CPS TO 2,000 CPS; 1-HOUR CYCLE; 1 CYCLE PER ORIENTATION; 3 ORIENTATIONS		AFTER 2 HRS 1 FAILURE. AFTER COMPLETION, 3 FAILURES.

Power step at V_{CB} = 20 V. will not be included in Phase II, since the legitimate rejects which developed at this condition (inversion layers and opens) would appear in the voltage plus temperature stress and the high temperature alone or high temperature plus mechanical type stresses which are to be a part of Phase II.

High current/power step-stresses ("d" and "e" of Figure 3) will not be repeated, because almost 100% of the failures showed evidence that the gold-silicon eutectic had been reached.

Temperature step with V_{CB} in avalanche at I_C = 2 mA. will not be repeated, as there is apparently no way to suppress oscillations. Also, such a burn-in would not be practical, since units would have to be individually set to the correct current.

Phase II - Proposed Program.

Figures 5A and 5B present a possible Phase II Program. Information from these stresses will determine stress conditions and sample sizes for the Phase III final reliability estimation experiments shown in Figure 6. As mentioned previously, Phase II will also determine the effectiveness of two screens, and will provide a measure of product improvement over the Contract period.

Since more devices will be required for Phase II than had originally been planned for this Phase, it was decided to run the PRE-TEST SEQUENCE shown in Figure 5A in order to plan TEST SEQUENCE (Figure 5B) sample flows with increased efficiency. Devices used for the tests described in Figure 5A will not, in some respects, meet the detailed electrical specification of the 2N2193 that will be involved in the TEST SEQUENCE of Figure 5B. They will, however, provide information on failure rates to be expected later. The Phase I step-stresses were of little value in this respect.

Experiment 1 (Figure 5A) will attempt to determine the extent to which devices subjected to a 200°C. and 300°C., 200-hour bake have been mechanically weakened. This information will help in deciding whether the voltage plus temperature screens of Experiments A1 and A2 (Figure 5B) are too severe from a mechanical weakening standpoint, and will provide some indication on relative yield losses during the screening tests of A1 and A2. Experiment 1 will also provide some information on whether devices which pass a mechanical pre-screen are mechanically weakened.

Experiment 2 (Figure 5A) is intended to anticipate failure rates on life tests chosen for Experiment A3, and the relationships of these various failure rates to one another. This information will facilitate increased efficiency in sample placement in TESTS A1, A2 and A3.

The circuit used for all Phase II life tests is shown in Figure 7 below. It is the same circuit as that which was used for the Phase I 20 - Volt power step-stress.

FIGURE 5A - PROPOSED PRE-TEST EXPERIMENTS.

Approximate Number of Devices

1A - 125 | 200°C. 200 Hours

- 62 * | 20 kG 1 Minute | * | 35 kG 1 Minute | * | 35 kG 5 Minutes | * | 50 kG 5 Minutes | *
- 63 Devices * | 35 kG 1 Minute | * | 35 kG 5 Minutes | * | 50 kG 5 Minutes | *

1B - 125 | 300°C. 200 Hours | (Centrifuge Same As Above)

* = Read for Opens and Shorts.

1C - 125 — Centrifuge

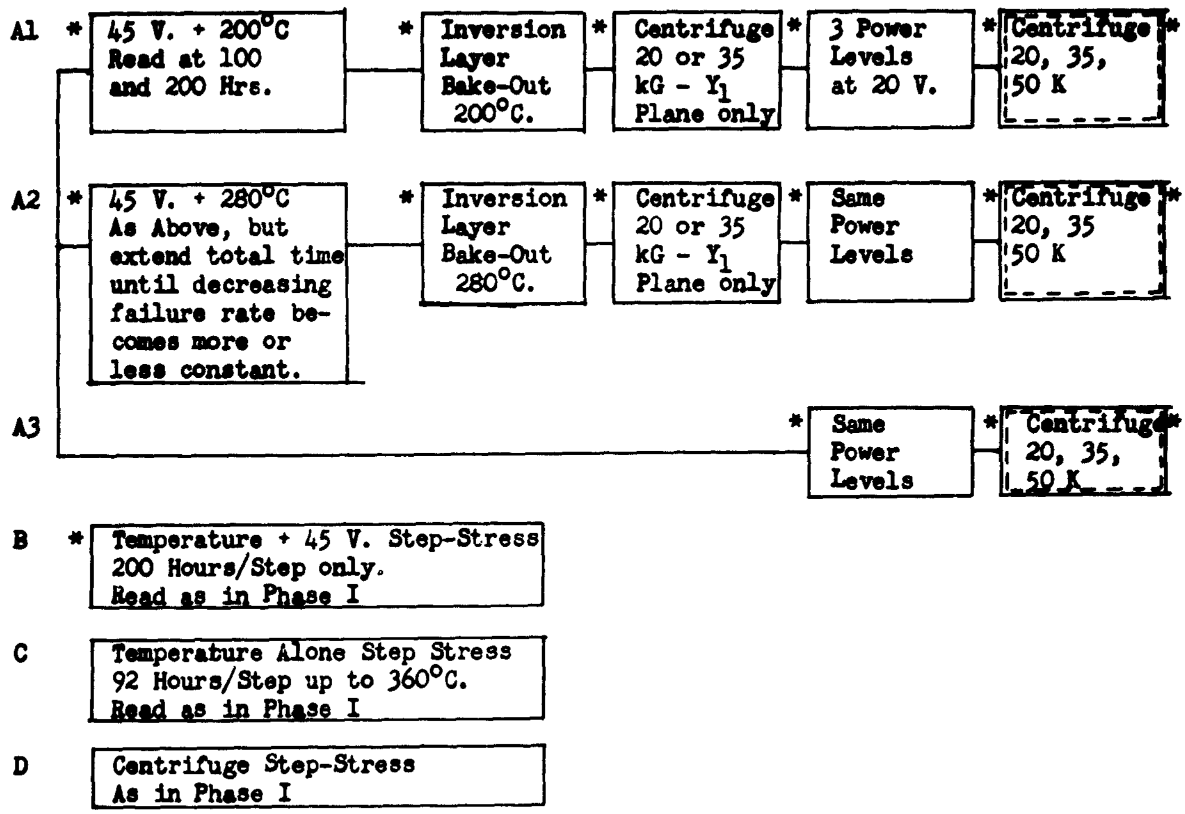
2A - 25	1.6 Watts, 20 V. 500 to 1,000 Hrs.	Read I_{CO}, I_{EO}, h_{FE} at downtimes 48, 168, 500, and 1,000 Hours.
2B - 25	1.4 Watts, 20 V. 500 to 1,000 Hrs.	Readings and Downtimes same as for 2A.
2C - 50	1.2 Watts, 20 V. 500 to 1,000 Hrs.	Readings and Downtimes same as for 2A.
2D - 100	1.0 Watts, 20 V. 500 to 1,000 Hrs.	Readings and Downtimes same as for 2A, except 48-hour omitted.
2E - 100	0.8 Watts, 20 V. 500 to 1,000 Hrs.	Readings and Downtimes same as for 2D.

3A - Devices from 92 and 192-hours/step Phase I, 45 V. + Temperature.

Devices from same Date Codes as above, but not previously subjected to 45 V. + Temperature.

→ 1.6 Watts, 20 V. 1,000 Hrs.

FIGURE 5B - PROPOSED PHASE II EXPERIMENTS.



* = Read I_{CO}, I_{EO}, h_{FE}, $V_{CE}(SAT)/V_{BE}(SAT)$, BV_{CEO}.

FIGURE 6 - PHASE III FINAL RELIABILITY ESTIMATION.

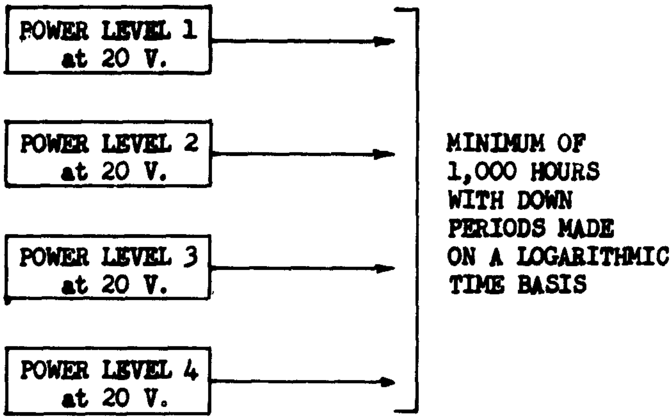
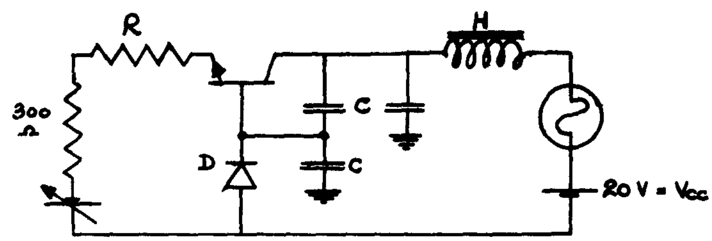


FIGURE 7



Two tests (1.6 and 1.4 watts) may be conducted in runaway, with voltages and power recorded, and three tests will be conducted in the stable region. This information will determine whether a failure versus stress curve is continuous over both stable and runaway power. If a continuity does exist, unstable conditions may be used in Experiment A, in order to obtain valid information from the least number of devices. If a continuity does not exist, then the three stable conditions (2C, 2D and 2E) will still enable the most efficient choice of sample sizes, stresses and proportioning of samples between stresses, to be made in Experiment A.

Experiment 3 will provide some indication of the degree to which a voltage plus temperature stress is successful in weeding out potential life test failures. More exactly, it will help to determine the increased sample size which we shall have to make available on A1 and A2 life tests over the sample size on A3, in order to be able to detect some degradation on A1 and A2 life tests.

Experiments A to D - Discussion.

The screening experiments are shown in A1 and A2, with A3 as a control (See Figure 5B). Note that the experiments differ only in that A2 uses 280°C. with voltage to detect inversion layers, whereas A1 uses only 200°C. with voltage. If pre-tests show that devices subjected to 280°C. are mechanically weakened, experiment A2 will not be conducted. A2 may also be abandoned if pre-tests indicate the danger of inconclusive information from A1 and A3.

A record will be made of the change in I_{CO} caused by the inversion screen, but no devices will be removed. All of the devices will then proceed to the temperature alone bake-out, which generally recovers the inversion layer type of failure. The devices will then be centrifuged at a level determined by pre-test and other information available and/or by centrifuging the A1 and A2 devices first in small pilot quantities at higher levels. If the pilot quantities should experience no great yield loss, then the main body of the devices would be subjected to the higher G level.

The devices in each of the three segments of the screening experiment would then pass to a series of three operating life stresses. The conditions and sample proportions would be determined by pre-test experiments 2 and 3. At the present time, no on/off cycling is planned, either for the pre-tests or for the tests, although this schedule may be changed if the experiments indicate that no voltage or current transient harm can be done to the devices. If cycling is added later, it would be performed on the emitter only; collector voltages would be maintained at all times, so that on an off-cycle inversion layers would be frozen in while the devices were cooling down.

A centrifuge test would possibly follow the operating life tests. This would provide some information on the amount of mechanical damage done to the devices by the sum total of screening experiments and accelerated life tests.

Experiments D, E and F have been previously discussed. They are identical to three Phase I experiments and are included for comparison with Phase I, to determine product improvement.

Phase III - Proposed Program.

Although it was originally the intent of the program to use Phase II to design a 2 x 3 factorial design experiment in voltage and power, recent indications are that the device reliability is such that tremendous sample sizes would be required to obtain significant information. Therefore, unless Phase II indicates differently, it is proposed that the final experiment contain only one collector voltage, probably 20 Volts.

E. Conclusions Because of the inherent high reliability of this type of transistor, the step-stresses of Phase I have proved to be ineffective, and this report discusses a possible substitute plan.

F. Program for next Quarter The present intent is to start the substitute plan.

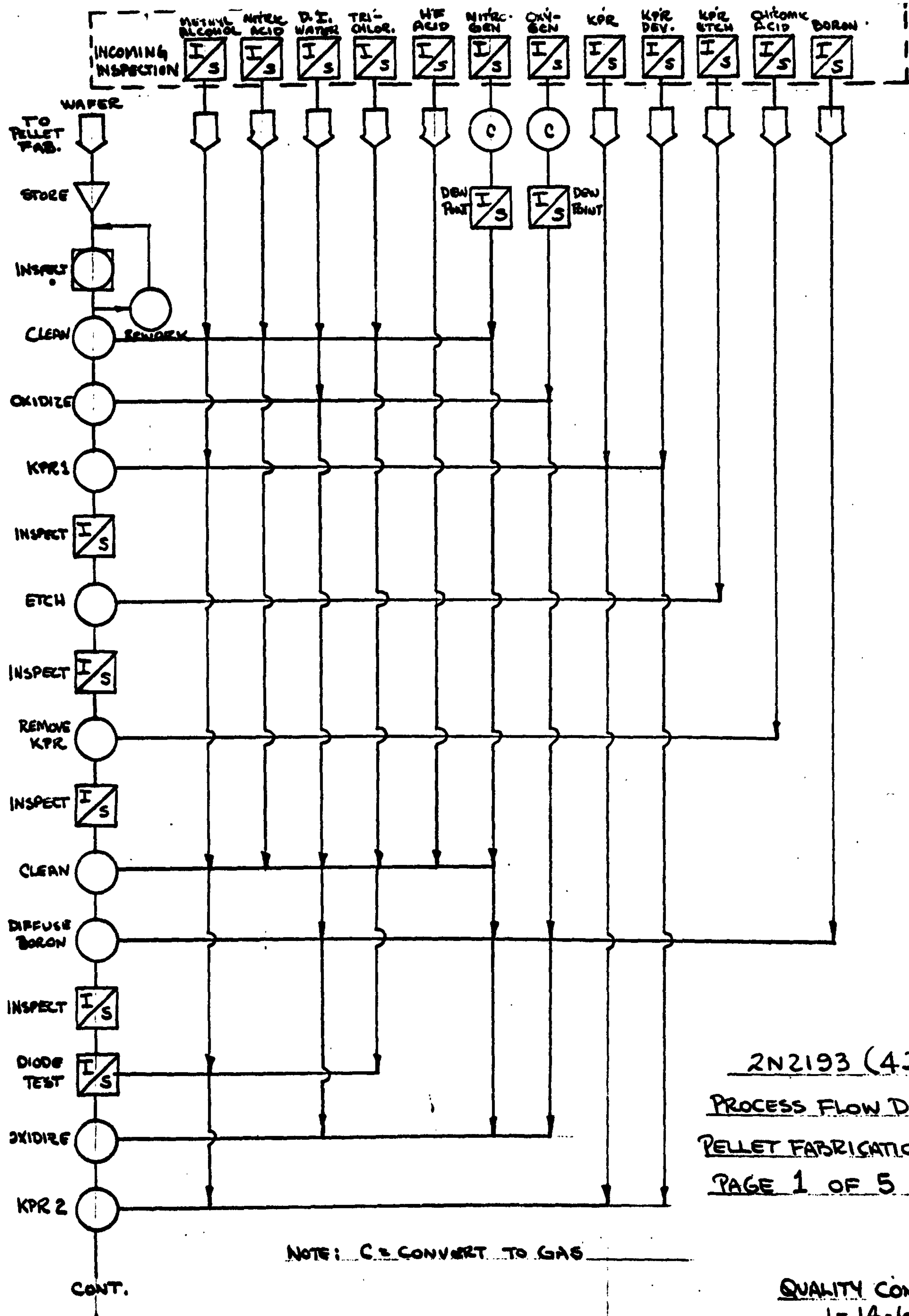
X. AREA OF WORK - INSPECTION AND QUALITY CONTROL PLAN.

1 A. Work Item - Process Flow Diagrams.

B. Abstract - During this work period, process flow diagrams were completed which reflect processing of material from receipt of the wafer to the shipping of finished transistors.

C. Purpose - The objective of this work item is to outline areas where additional documentation is required to complete Section III of the Inspection and Quality Control Plan.

F. Program for next Quarter - Using the Process Flow Diagrams as a guide, inspection and test operations will be coded and supporting detailed inspection procedures will be prepared where necessary. In addition, Sections I and II of the Inspection and Quality Control Plan will be completed.



2N2193 (4JD11C)

PROCESS FLOW DIAGRAM

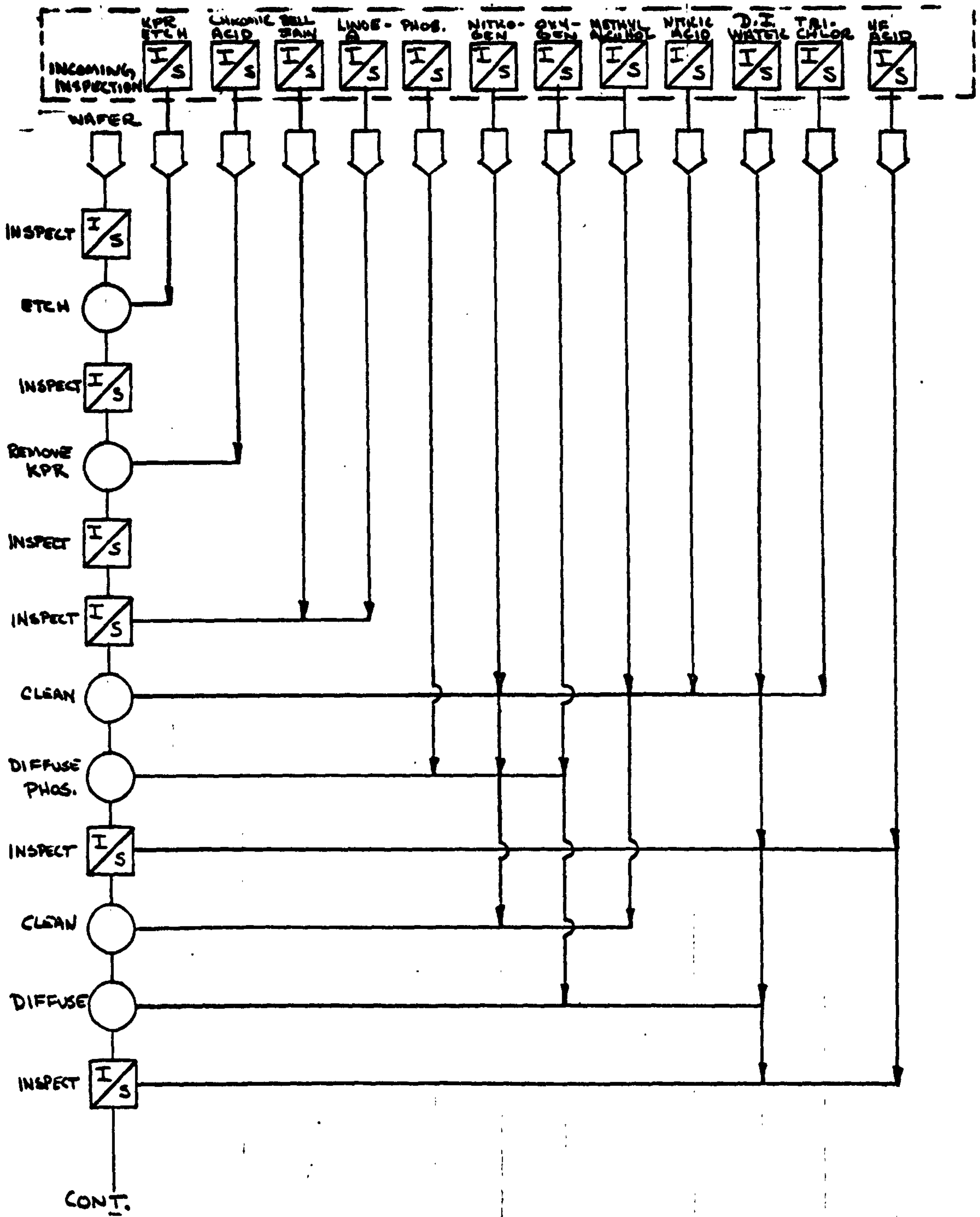
PELLET FABRICATION AREA

PAGE 1 OF 5

NOTE: C = CONVERT TO GAS

QUALITY CONTROL

1-14-63



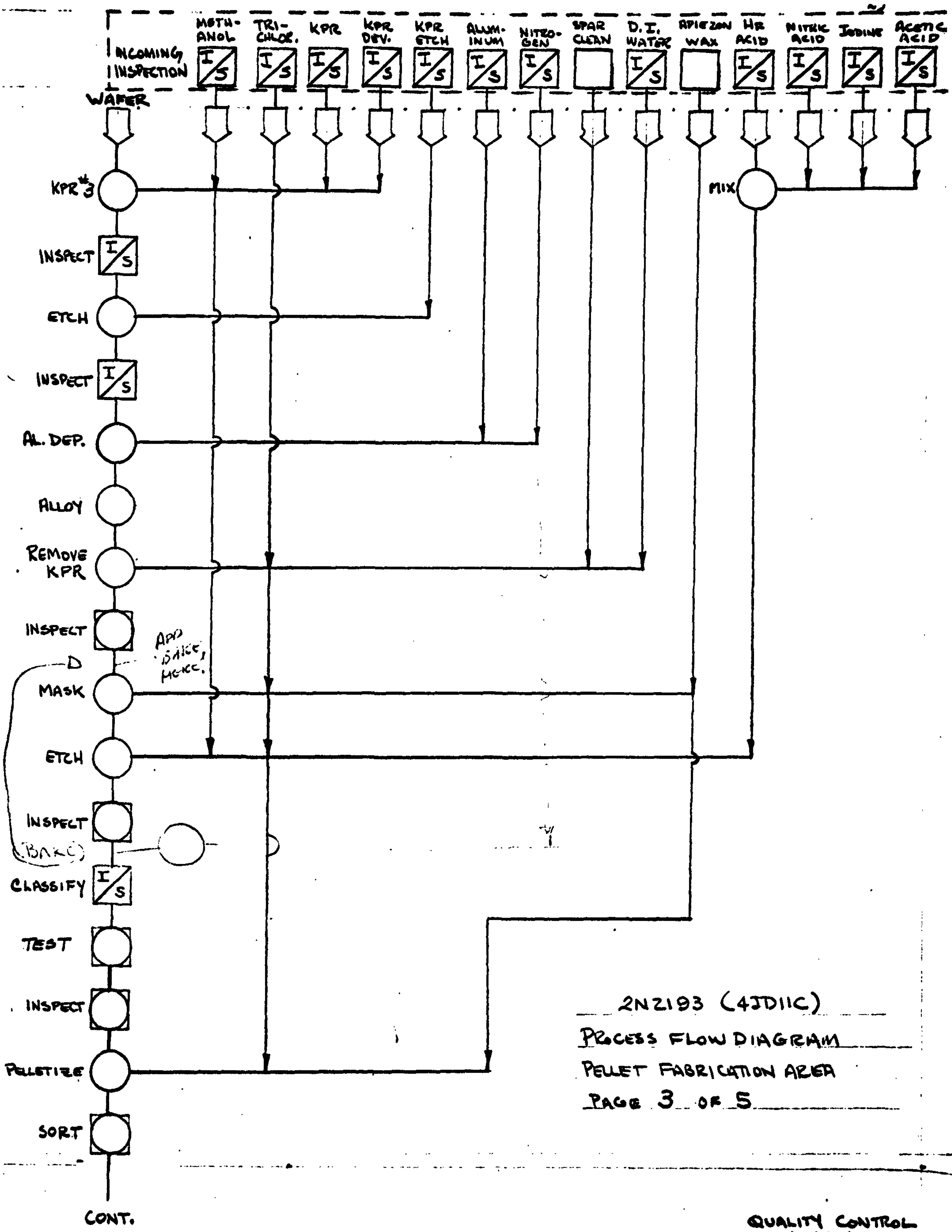
2N2193 (4JD11C)

PROCESS FLOW DIAGRAM

PELLET FABRICATION AREA

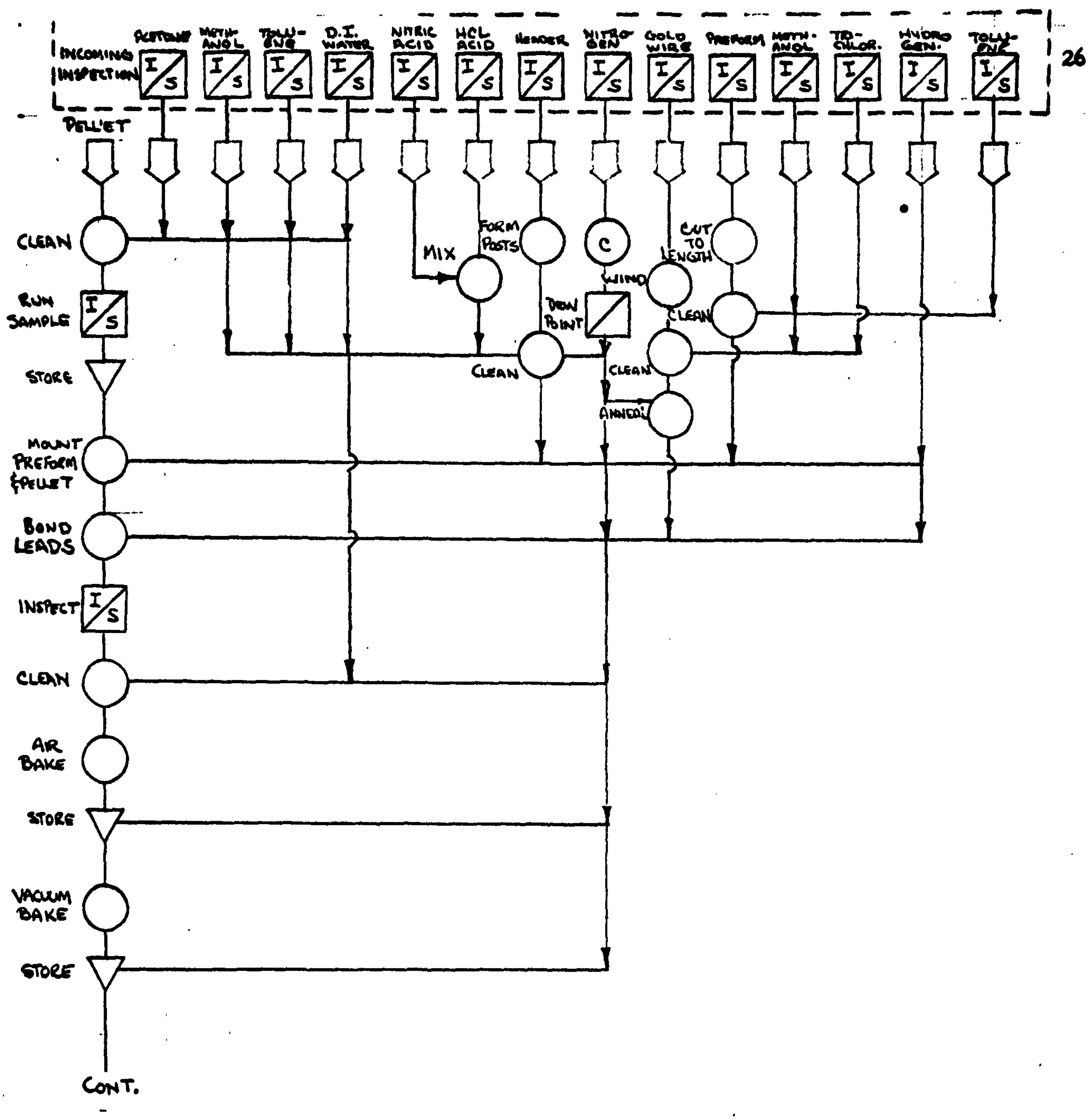
PAGE 2 OF 5

QUALITY CONTROL
1-16-63



2N2193 (4JD11C)
PROCESS FLOW DIAGRAM
PELLET FABRICATION AREA
PAGE 3 OF 5

QUALITY CONTROL
1-14-63



NOTE: C = CONVERT TO GAS

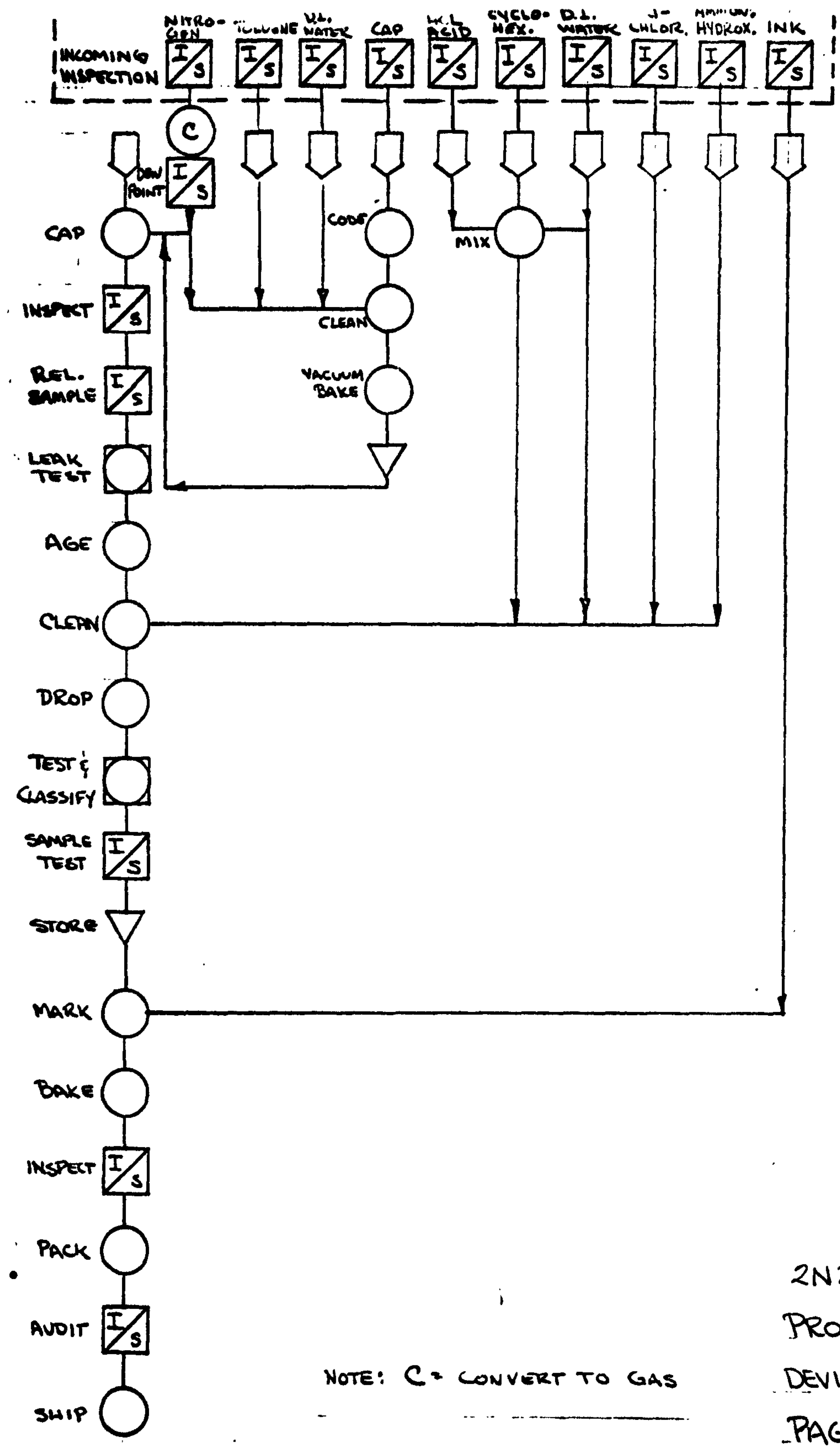
2N2193 (4JD11C)

PROCESS FLOW DIAGRAM

DEVICE FABRICATION AREA

PAGE 4 OF 5

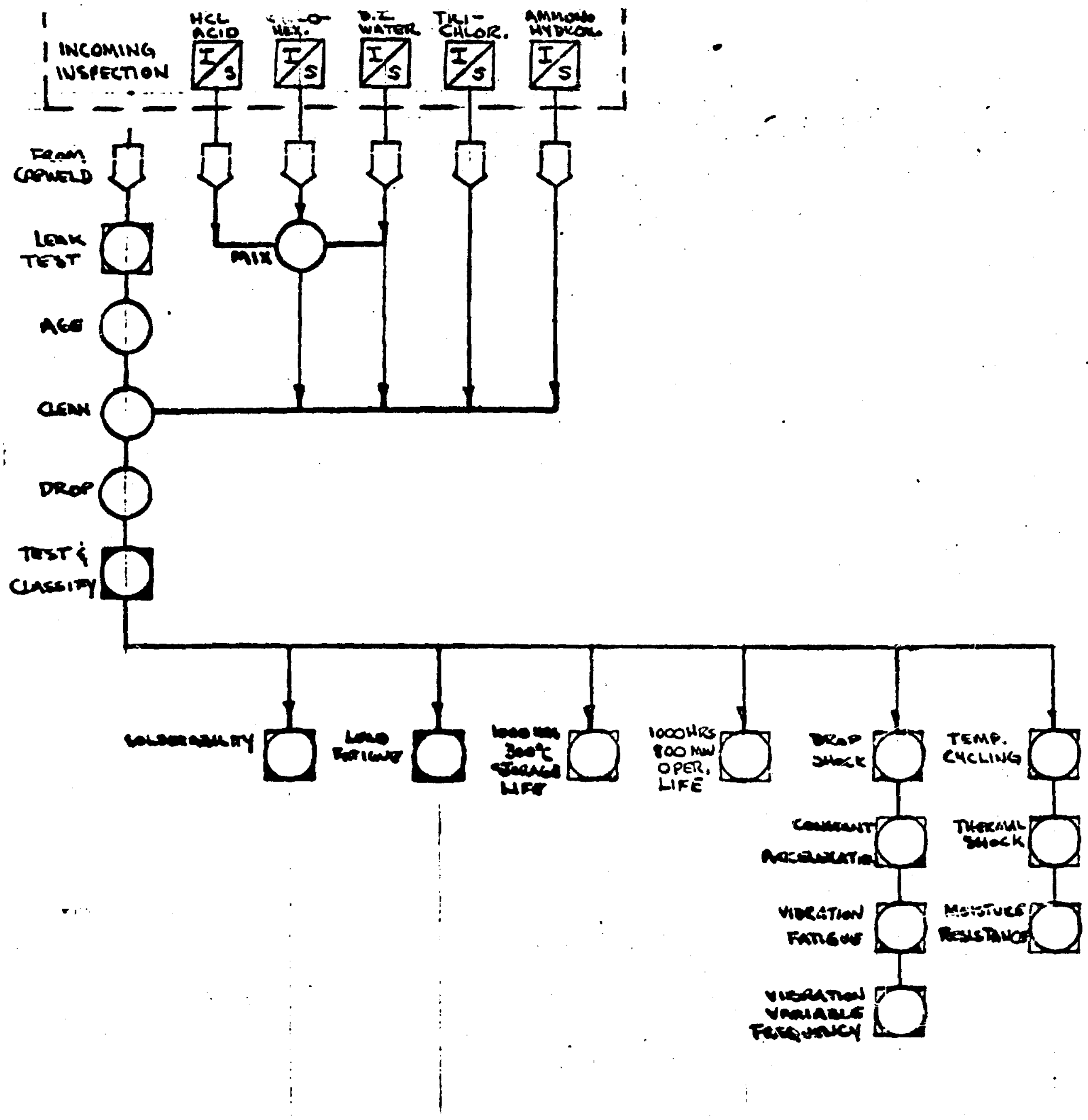
QUALITY CONTROL
1-16-63



NOTE: C = CONVERT TO GAS

2N2193 (4JD11C)
PROCESS FLOW DIAGRAM
DEVICE, MARK, PACK & SHIP AREA
PAGE 5 OF 5

QUALITY CONTROL
1-16-63



2N2193 (4JD11C)

PROCESS FLOW DIAGRAM

RELIABILITY TESTING

PAGE 1 OF 1

QUALITY CONTROL
1-16-63

PROFESSIONAL PERSONNEL

and

TOTAL APPLIED EFFORT

for period covering

1 November, 1962 - 31 January, 1963.

Personnel	Manhours
Dr. A. R. DiPietro	4,185 total
J. L. Durso	
F. K. Glasbrenner	
T. E. Jacobs	
R. T. Kobler	
R. H. Lanzl	
C. E. Logan	
J. C. Richardson	
R. E. Smith	
J. F. Wholey	
A. Poe	
H. M. Calder	

U. S. ARMY ELECTRONICS MATERIEL AGENCY.

Production Engineering Measure

DA-36-039-SC-86727

Silicon Grown Diffused Transistor

2N336

The purpose of the Production Engineering Measure Program is to improve the production techniques on the Silicon Grown Diffused Transistor type 2N336, with a maximum failure rate of 0.01% per 1,000 hours at a 90% confidence level at 25°C. as an objective.

Third Quarterly Report

31 October 1962
31 January 1963.

General Electric Company
Semiconductor Products Department
Syracuse, New York.

Report Prepared by: F. J. Potter

Approved by: J. R. McLaughlin

TABLE OF CONTENTS

1. ABSTRACT

Passivation - The automatic passivation equipment has been in operation since the publication of the last report. Its evaluation is in progress and will be reported below.

High Temperature Main Sealing - The procurement and installation of welding equipment is complete. Experimentation with cap loading attachment design is under way.

Experimentation and Evaluation - The encapsulation experiment has been completed. The evaluation has indicated an optimum flush temperature of 250°C., with a flush time of 24 seconds.

The reliability evaluation of the automatic passivation system has completed 500 hours. Comparison with the prototype shows no statistically significant difference between the two systems. The temperature plus voltage screen shows a marked ability to weed out potential I_{CBO} "up-shifters".

Characteristic Distribution - Weekly parameter distributions of fhfb, hrb, hob, NF, V_{CE}, Cob, hfe, BV_{CBO}, BV_{EBO}, I_{CBO} and I_{CBO} at 150°C. are included for weeks 44 through 52 of 1962, and weeks 1 and 2 of 1963.

2. PURPOSE

The purpose of the Production Engineering Measure Program is to improve the production techniques on the Silicon Grown Diffused Transistor type 2N336, with a maximum failure rate of 0.01% per 1,000 hours at a 90% confidence level at 25°C. as an objective.

In the fabrication of semiconductor devices there are inevitably critical process steps which, due to process variability, exert an influence on test yields and also on long range reliability. In order to achieve the reliability objective of this program, two key process steps have been singled out to maximize process control. By redesign of initial production equipment in these two areas, the latest processing techniques can be incorporated, while minimizing process variability, and at the same time greatly increasing production capability. The two specific work areas referred to above are Surface Passivation and High Temperature Main Sealing.

The objectives of this report are now noted.

2.1 PASSIVATION

Installation of equipment which will...

1. Permit the incorporation of the latest processing techniques.
2. Minimize process variability.
3. Increase production capability.

2.2 HIGH TEMPERATURE MAIN SEALING

Installation of main seal welding equipment which will meet the process requirements, defined as necessary to achieve highly reliable device performance, and which will also provide for volume production.

2.3 EXPERIMENTATION AND EVALUATION

2.3.1 Encapsulation Experiment. - Optimization of flush temperature and time for the encapsulation or main seal welding process.

2.3.2 Reliability Experiment. - Determination of the reliability of the automatic passivation process versus the prototype method.

2.4 CHARACTERISTIC DISTRIBUTIONS

The establishment of a system to monitor the electrical parameter distributions on the 4JD4C line where the 2N336 is produced.

3. NARRATIVE AND DATA

3.1 PASSIVATION

The automatic passivation equipment was completely installed and put into production during the period covered by the second quarterly report. The evaluation of the equipment is still under way and the progress to date is reported below.

3.2 HIGH TEMPERATURE MAIN SEALING

Work on this contract during the third quarter has been concentrated on the final assembly of the main seal welding machine, and on making preliminary runs to check for operation. The main castings on each of the twenty stations of the welding machine turret were sent to a specialty outside vendor to have the bearing seats coated with aluminum oxide and to have the bearings fabricated. Due to the holiday season and the subsequent bad weather, the return of these castings was delayed for three weeks. Fortunately, no troubles were encountered in the assembly and the re-assembly was completed and the machine installed only one week behind plan.

Initial runs indicate that the temperature of the purge gas which was originally sought is readily obtainable. The machine was operated for eight hours with gas temperatures above 375°C. with no apparent difficulties. The welding capability of the machine has not been impaired. The first lot of units welded were tested through "Radiflo" with no rejects.

A prototype escapement mechanism for positioning the transistor cap into the upper electrode has been fabricated, and a second approach has been started in fabrication. These two approaches to cap loading will be explored during the next quarter in an effort to provide a reliable cap loader for this welding operation.

The regular process checking and evaluation program for the high temperature main seal welding operation will proceed as programmed, and will not be affected by the cap loader program.

3.3 EXPERIMENTATION AND EVALUATION

The following pages contain reports on:-

3.3.1 - Encapsulation Experiment,

3.3.2 - Reliability Experiment.

3.3.1 ENCAPSULATION EXPERIMENT

The purpose of this experiment is to optimize the High Temperature Main Sealing process. Eleven various capping conditions were used to produce eleven lots at 80 units per lot. Keeping in mind the capabilities of the twenty-station indexing type rotary welding machine, a spectrum of various flushing temperatures and times were chosen. A control lot using the standard process was also run in order to monitor the experiment. All 880 units were entirely randomized before encapsulation and a three-head welder was used, since the twenty-station rotary welder was still in the process of being modified.

The following capping conditions were run:-

1.	Controls	
2.	40°C.	24 seconds
3.	40°C.	72 seconds
4.	40°C.	216 seconds
5.	150°C.	24 seconds
6.	150°C.	72 seconds
7.	150°C.	216 seconds
8.	300°C.	24 seconds
9.	300°C.	72 seconds
10.	300°C.	216 seconds
11.	300°C.	600 seconds

Lots 2 through 10 were used to form a three-by-three experiment to study the effect of two variables (time and temperature) at three levels. After a normal aging cycle, each lot was screened (obtaining yield information) then split and placed on one of the following life tests, 200°C. storage or 500 milliwatts power. I_{CBO} and h_{FE} were read after 0, 168, 500 and 1,000 hours. A computer program was used in order to obtain ΔB shift in percent with respect to the zero-hour reading for each readout time. The program was also used to rank the units in each lot and to yield percentile information.

For the ΔB shift on 200°C. storage and 500 milliwatt life tests, a two-way analysis of variance, with N observations per combination will be performed. A two-way analysis of variance is a statistical test for significant differences between means with respect to each of two factors and also a joint effect (interaction) of these two factors.

The following computational procedure will be used to analyze the data.

		FACTOR B (Time)				
	J \ K	β_1	....	β_K	....	β_C
FACTOR A (Temperature).	α_1	X_{111} X_{211} ...... X_{i11}				
	....					
	α_J			X_{1JK} X_{2JK} ...... X_{iJK}		
	....					
	α_R					X_{1RC} X_{2RC} ...... X_{iRC}

A measured variable X is classified according to the two factors A (flushing temperature) and B (flushing time). There are R categories of A, and C categories of B. For cell $\alpha_J \beta_K$, where J = 1,2,....R, and K = 1, 2,....C, there are n_{JK} observations. Thus X_{ijk} is the i'th measurement in cell $\alpha_J \beta_K$, where i = 1, 2,.... n_{JK}. For the analysis of this three-by-three experiment, R = 3 and C = 3.

The following assumptions are made in using this procedure.

1. Each cell $\alpha_J \beta_K$ represents a random sample having a normal distribution and the standard deviation of all these distributions have the same values.

2. The number of observations for each cell, n_{JK}, must be approximately the same.

(1). Calculate the row totals.

$$A_J = \sum_{K=1}^{C} \sum_{i=1}^{n_{JK}} X_{iJK}$$

(2). Calculate the column totals.

$$B_K = \sum_{J=1}^{R} \sum_{i=1}^{n_{JK}} X_{iJK}$$

(3). Calculate the within combination totals.

$$W_{JK} = \sum_{i=1}^{n_{JK}} X_{iJK}$$

(4). Calculate.

$$n_J = \sum_{K=1}^{C} n_{JK} \qquad \text{(number of readings in row J)}$$

$$n_K = \sum_{J=1}^{R} n_{JK} \qquad \text{(number of readings in column K)}$$

$$N = \sum_{K=1}^{C} \sum_{J=1}^{R} n_{JK} \qquad \text{(total number of readings)}$$

(5). Calculate the crude sum of squares.

$$\text{C.S.S.} = \sum_{K=1}^{C} \sum_{J=1}^{R} \sum_{i=1}^{n_{JK}} X_{iJK}^2$$

(6). Calculate the overall total.

$$T = \sum_{J=1}^{R} A_J = \sum_{K=1}^{C} B_K = \sum_{K=1}^{C} \sum_{J=1}^{R} W_{JK}$$

(7). Calculate the crude sum of squares between columns.

$$\text{C.S.S.C} = \sum_{K=1}^{C} \frac{B_K^2}{n_K}$$

(8). Calculate the crude sum of squares between rows.

$$\text{C.S.S.R.} = \sum_{J=1}^{R} \frac{A_J^2}{n_J}$$

(9). Calculate the crude sum of squares between combinations.

$$\text{C.S.S.K.} = \sum_{K=1}^{C} \sum_{J=1}^{R} \frac{W_{JK}^2}{n_{JK}}$$

(10). Calculate the correction factor due to the mean.

$$= \frac{T^2}{N}$$

(11). From the quantities above find:

(A) SSC = (7) - (10) = C.S.S.C. - C.F. = sum of squares for B (columns)
(C - 1) degrees of freedom.

(B) SSR = (8) - (10) = C.S.S.R. - C.F. = sum of squares for A (rows)
(R - 1) degrees of freedom.

(C) SST = (5) - (10) = C.S.S. - C.F. = total sum of squares.

(D) SSt = (9) - (10) = C.S.S.K. - C.F. = sub-total sum of squares.

(E) SSRC = SSt - SSR - SSC = sum of squares for AB interaction (Column X row)
(R - 1)(C - 1) degrees of freedom.

(F) SSE = SST - SSt = sum of squares of residual (error)
(N - RC) degrees of freedom.

(12). Mean square of A = MSA = $\frac{SSR}{(R-1)}$

(13). Mean square of B = MSB = $\frac{SSC}{(C-1)}$

(14). Mean square of AB = MSAB = $\frac{SSRC}{(R-1)(C-1)}$

(15). Mean square of E = MSE = $\frac{SSE}{(N-RC)}$

(16). $F_{AB} = \frac{MSAB}{MSE}$ (Test for interaction).

(17). $F_A = \frac{MSA}{MSE}$ (Test for Temperature Effects).

(18). $F_B = \frac{MSB}{MSE}$ (Test for Time Effects).

The Δ B shift at 1,000 hours for the 200°C. storage condition is now analyzed. The raw data is tabulated in the following table (Table 1).

TABLE I.

SUMMARY OF Δ B SHIFT IN PERCENT FOR 1,000 HOURS, 200°C. STORAGE.

FACTOR A (Temperature)	FACTOR B (Time) 24 seconds	72 seconds	216 seconds	
40°C.	$X = +186$ $X^2 = 1664$ $N = 40$	$X = +349$ $X^2 = 8096$ $N = 38$	$X = +414$ $X^2 = 6143$ $N = 40$	
150°C.	$X = +290$ $X^2 = 2884$ $N = 40$	$X = +377$ $X^2 = 4111$ $N = 40$	$X = +494$ $X^2 = 7742$ $N = 40$	
300°C.	$X = +291$ $X^2 = 5637$ $N = 40$	$X = +508$ $X^2 = 22846$ $N = 39$	$X = +621$ $X^2 = 24155$ $N = 38$	

After analyzing the above data the following table is obtained.

TABLE II.

ANALYSIS OF VARIANCE TABLE FOR Δ B SHIFT AT 1,000 HOURS FOR 200°C. STORAGE.

Source	Sum of Squares	Degrees of Freedom	Mean Square	Test
Between Times	2,629	2	1,314.5	$F_B = 10.27$
Between Temperatures	999	2	499.5	$F_A = 3.90$
Interaction	265	4	66.3	$F_{AB} = 0.52$
Within Combinations	44,284	346	128.0	

It can be shown that MSAB/MSE is distributed as an F random variable with (R - 1) (C - 1) and (N - RC) degrees of freedom when the hypothesis of no interaction is true. The hypothesis that there is no interaction between temperature and time is rejected if

$$F_{AB} = \frac{MSAB}{MSE} \geq F\alpha;\ (R-1)(C-1),\ (N-RC)$$

where α is the level of significance. α can be defined as the risk of rejecting

the hypothesis when the hypothesis is, in effect, true. If the hypothesis of no interaction is rejected, tests for significance of row and column effects are irrelevant.

Since F_{AB} = 0.52 is less than $F_{.10; 4,346}$ = 1.96 then it can be stated that there is no interaction. By applying these F tests it is possible to estimate whether the variations between cells is greater than would be expected if all the cells were obtained from the same population. Testing the other two F ratios for temperature and time effects reveals that there is a 0.025 significance level between temperatures and a 0.001 significance level between times. Therefore it is concluded that flushing temperature and time are significant factors in Δ B shift at 200°C. storage, with time being the most important factor. It can be seen from Table I that increasing temperature or time has the net effect of increasing the amount of positive Δ B shift. It is noted that from a reliability standpoint a minimum Δ B shift is desirable.

The Δ B shift at 1,000 hours for 500 milliwatts was analyzed in a similar manner. It was found, however, that there was interaction at a 0.05 significance level. For this reason, the F test for temperature and time effects was not applied, since the results would be meaningless because of this significant interaction.

I_{CBO} after the normal aging cycle can be seen to have an interaction between time and temperature. This can be seen from the following table of median I_{CBO}.

TABLE III. I_{CBO} MEDIANS.

	24 seconds	72 seconds	216 seconds
40°C.	21.4	26.1	5.1 millimicroamperes
150°C.	13.7	14.3	10.7 millimicroamperes
300°C.	4.4	14.3	11.3 millimicroamperes

Median found from approximately 80 units per cell. Because of this interaction, no F test for temperature or time effects is applied. It is noted that the 300°C. and 24 second encapsulation condition yields the lowest I_{CBO} median.

Using the evaluated data, the optimum encapsulation conditions will now be found, considering the following factors.

A. Optimum from productivity standpoint.

In order to increase the production capacity as proposed, a short time flushing cycle would be optimum.

B. Optimum from yield standpoint.

From Figure 3.3.-1, it is concluded that the 300°C. flush temperature is to be avoided because of its poor yield relative to the controls.

However, sample production runs at 300°C. and 15 seconds indicate that the yield is satisfactory. In order to provide a margin of safety, the 300°C. flushing temperature should be avoided.

C. Optimum from Δ B shift at 200°C. storage life test.

As an indication of reliability, as small a Δ B shift as possible is desired. Using the two-way analysis of variance technique, it was shown that increasing temperature and time has a significant effect on increasing Δ B shift, time being the more predominant factor. The optimum conditions would then appear to be primarily a short flushing time and a low flushing temperature.

D. Optimum from Δ B shift at 500 milliwatt power life test.

Since the two-way analysis of variance indicates a temperature and time interaction, no optimum conditions can be stated with confidence.

E. Optimum from I_{CBO} standpoint.

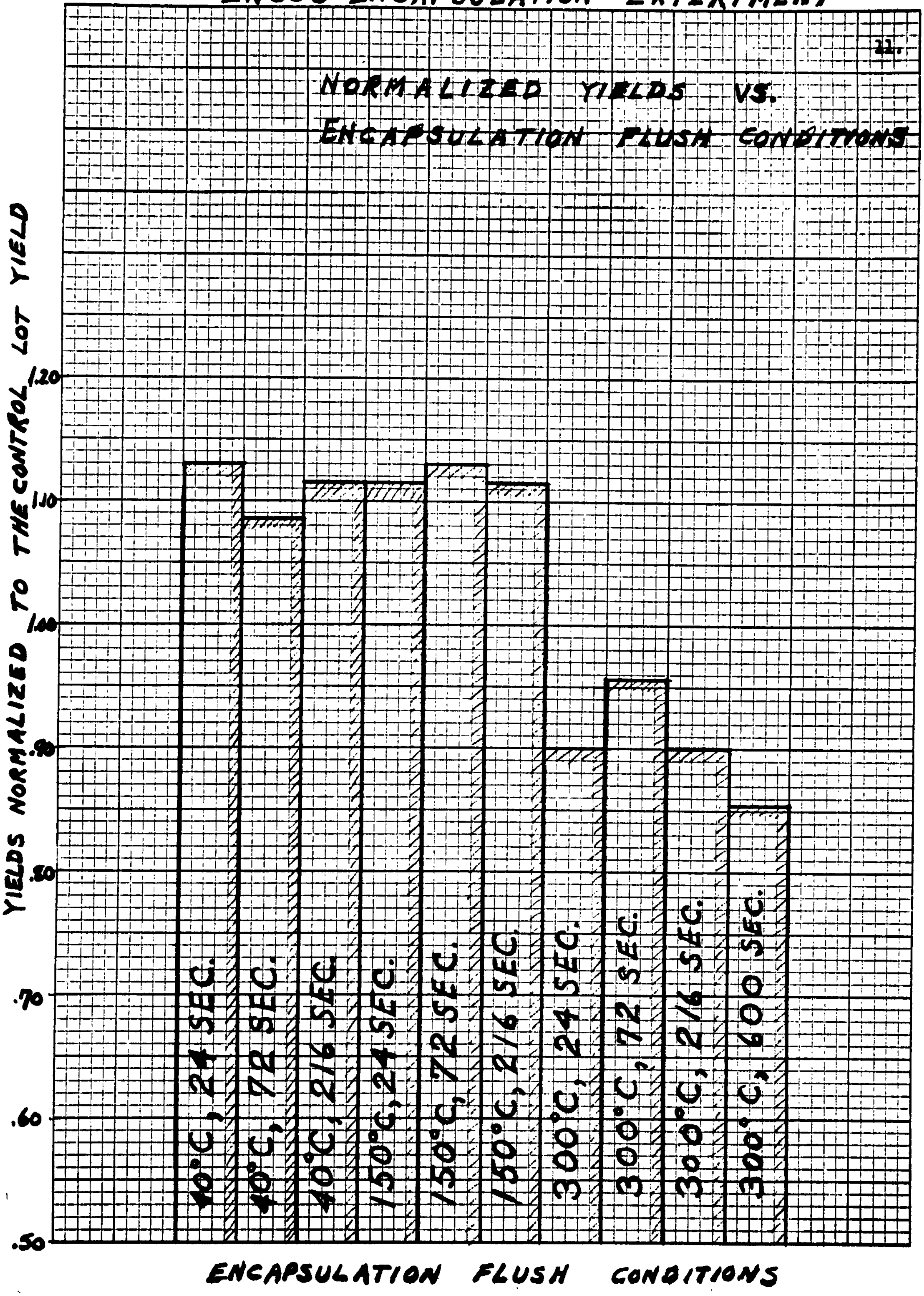
Although interaction does exist, it appears from Table III that a high temperature (300°C.) and a short time (24 seconds) flush would be optimum. It is also noted that sample production at 300°C. and 15 seconds likewise yields a lower I_{CBO} median. This lower I_{CBO} median will reflect itself in improved reliability.

Considering all of these factors, and compromising where necessary, it was decided that the following encapsulation conditions would be optimum:

Flush Temperature - 250°C.

Flush Time - 24 seconds.

2N336 ENCAPSULATION EXPERIMENT



70X100 1/10 Inch Divisions
GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y., U.S.A.
FN-521-A (8-50)

3.3.2 RELIABILITY EXPERIMENT

Evaluation of the newly installed automatic passivation system has begun. So far, units have been exposed to 500 hours of accelerated power and accelerated temperature storage tests.

This special line experiment is statistically designed, primarily, to compare the performance of those devices processed through the automated system with the performance of those processed through the prototype system. Performance is judged on a 1,000-hour minimum life test at an accelerated power level (760 milliwatts) and at an accelerated oven storage (250°C.). The design will further allow an evaluation of the effectiveness of a 100% applied stress screen of high ambient temperature (200°C.) with reverse bias collector voltage (45 V.) of 100-hour duration. Based on the extensive work of the High Reliability Minuteman Program on the grown diffused product type, 2N335, such stress screening was proved to be most effective in detecting and weeding out those potential failures (primarily of the n-inversion mechanism) which would occur on short-time accelerated power tests (e.g. 1,000 hours or less) or on extremely long-time operating power level tests (e.g. >10,000 hours). A simplified "tree type" diagram of the experimental design, with indicated sample sizes, is shown in Figure A.

A t-test analysis between the two independent systems of passivation, based on I_{CBO} increase after stress screening showed no statistical significance whatever. Figure B shows the extremely good fit to normality of log ΔI_{CBO}, thereby justifying the application of the Student's t-test. Along the ordinate of Figure B, the complement of the cumulative distribution function is represented (i.e., $1 - F(\log \Delta I_{CBO})$). From the least square fitted line shown, one could estimate the screen yields according to different definitions of a screen failure.

Preliminary analyses conducted between the two systems, based on the 500-hour accelerated life tests, show that the automatic passivation system is at least as desirable as the prototype system, if not more so. While no statistical significance could be demonstrated between the two systems, the automatic passivation data was more favorable, in that no failures (I_{CBO} exceeding 1 microampere) have been observed on either accelerated life test during the first 500 hours, while one failure on each of the accelerated life tests has occurred among the devices from the prototype passivation system. In addition, the I_{CBO} shift is somewhat less for the automatic system.

While no real differences have been discovered between the two systems, the effectiveness of the temperature plus voltage screen in weeding out the "up-shifters" of I_{CBO} is clearly established, particularly on the power operating test. For example, on the 760-milliwatt test combined over both passivation systems, 10.5% of the non-stressed screened units shifted by an amount greater than 50 millimicroamperes as compared to 1% for stress screened devices. Another interesting fact noted was the very strong correlation between I_{CBO} "up-shifters" on temperature with voltage which would recover on the stabilization bake and which are put on the 760-milliwatt test. Of the "up-shifters" (>50 millimicroamperes) occurring on the 500-hour power test, well over 90% of them revealed this up-shifting

tendency early on the temperature plus voltage test. An extensive report will be given at the completion of the experiment.

Future Plans.

Another special line experiment, concerning the encapsulation of the device, is presently getting under way and will be reported on in the next report.

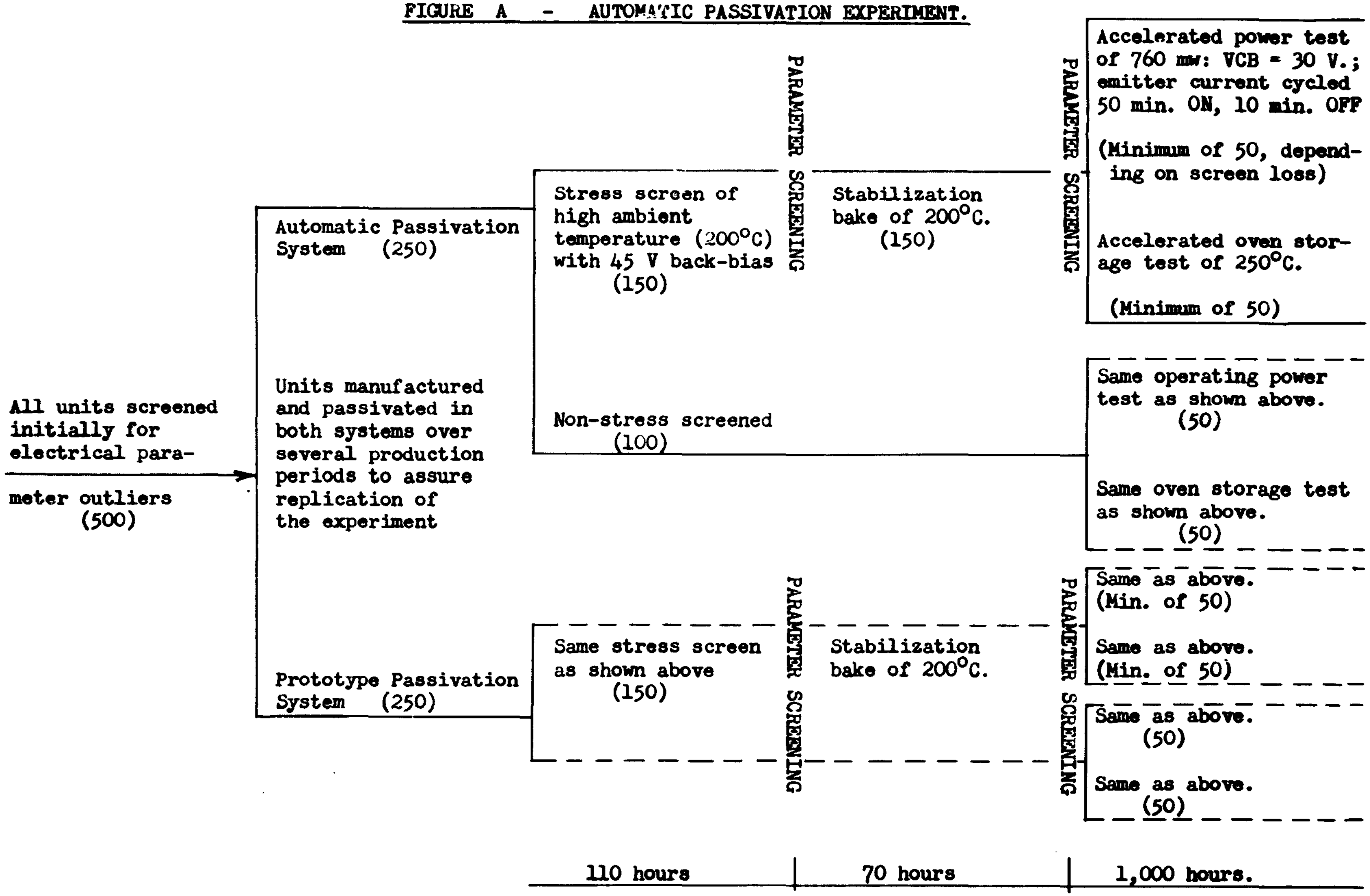
Tentative planning of the multi-level operating power tests have been completed, and units will be sampled for these high level tests once the evaluation of the special line experiments is completed and any necessary action taken.

All units will be carefully stress screened through a one-week duration of a high temperature with back-bias voltage, previously discussed above.

Approximately 1100 screened 2N336 devices will be subjected to high power operating stresses (intermittent and continuous operation) as depicted in Figure C.

It is expected that the application of the Arrhenius Model to the accelerated test data will meet with success, as was experienced in the Minuteman High Reliability Program. This technique will be fully described in subsequent reporting. Suffice it to say here that the application of the Arrhenius Model to accelerated test data allows one to ascertain true acceleration over the range of only those stress conditions aligned on an Arrhenius plot, i.e., the log of failure rate versus reciprocal junction temperature on an absolute scale.

FIGURE A - AUTOMATIC PASSIVATION EXPERIMENT.



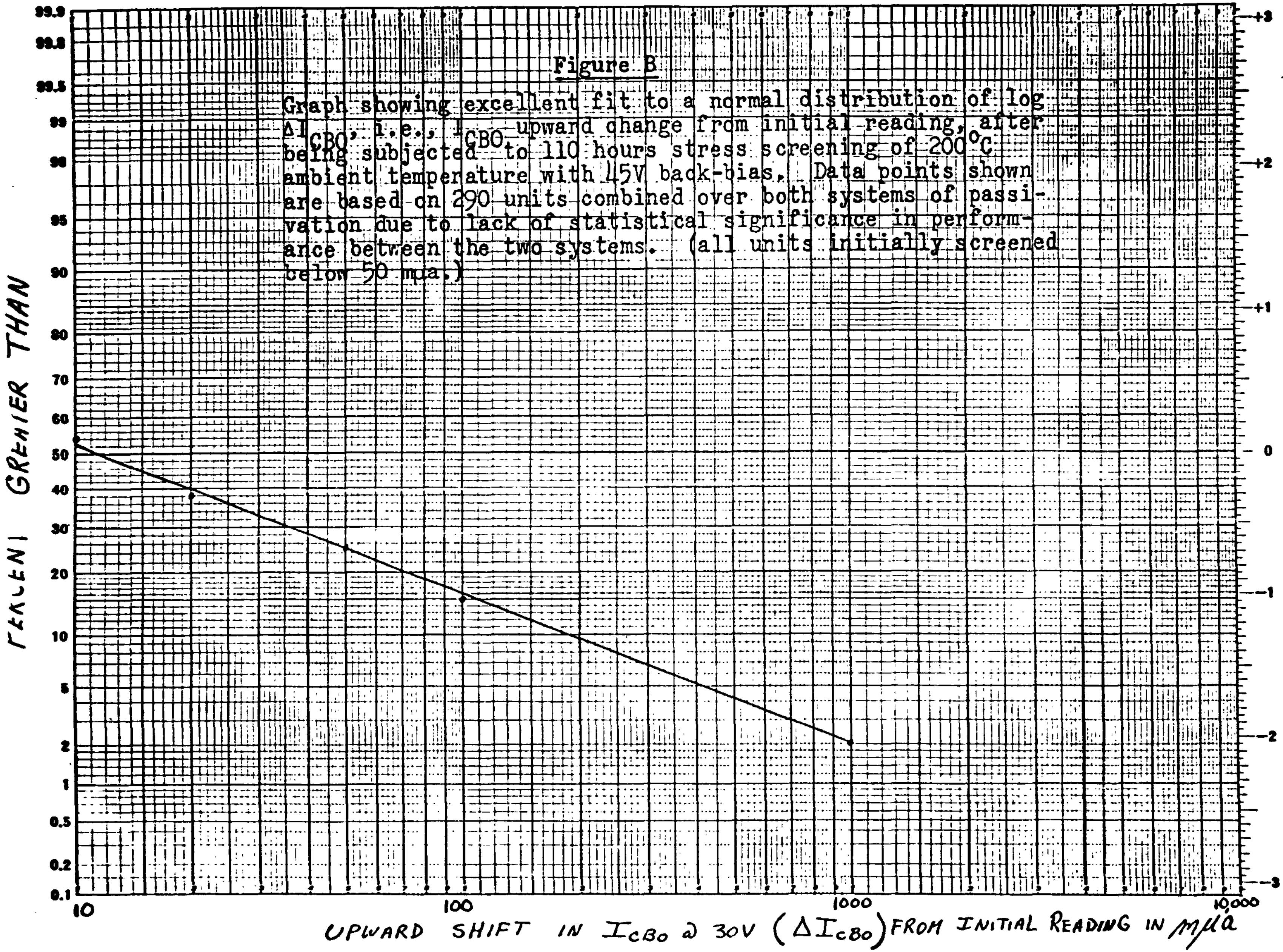


Figure B

Graph showing excellent fit to a normal distribution of log ΔI_{CBO}, i.e., I_{CBO} upward change from initial reading, after being subjected to 110 hours stress screening of 200 °C ambient temperature with 45V back-bias. Data points shown are based on 290 units combined over both systems of passivation due to lack of statistical significance in performance between the two systems. (all units initially screened below 50 mμa.)

FIGURE C. - FULL DESCRIPTION OF LIFE TEST CONDITIONS, MINIMUM DURATION, AND QUANTITY OF UNITS ASSIGNED TO THAT CONDITION.

Stress Cell and Minimum Duration in hours	Ambient Temperature °C.	Collector Voltage V.	Emitter Current mA.	Power Dissipation mw.	Calculated Junction Temperature using = .23 °C./mw	Cycle Rate (Emitter Current only)	No. of Units Assigned
1 5,000 Hours	25	30	16.7	500	140	50 min ON / 10 min OFF	250
2 5,000 Hours	25	30	16.7	500	140	None	200
3 3,000 Hours	25	30	21.7	650	175	50 min ON / 10 min OFF	200
4 3,000 Hours	25	30	25.3	760	200	50 min ON / 10 min OFF	100
5 3,000 Hours	25	30	25.3	760	200	None	100
6 1,000 Hours	25	30	32.7	980	250	50 min ON / 10 min OFF	100
7 1,000 Hours	25	30	32.7	980	250	None	100
8 1,000 Hours	25	30	40.0	1200	300	50 min ON / 10 min OFF	50
						TOTAL	1100

3.4 CHARACTERISTIC DISTRIBUTIONS

The attached report gives the weekly parameter distributions of BV_{EBO}, BV_{CBO}, h_{fe}, I_{CBO} at 25°C. and 150°C., and h_{fe} at -55°C. As stated in the last report, current gain h_{fe} has been recorded rather than h_{fb}, and BV_{EBO} at I_E = 100 microamperes has been recorded rather than I_{EBO} at V_{EB} = 1 Volt.

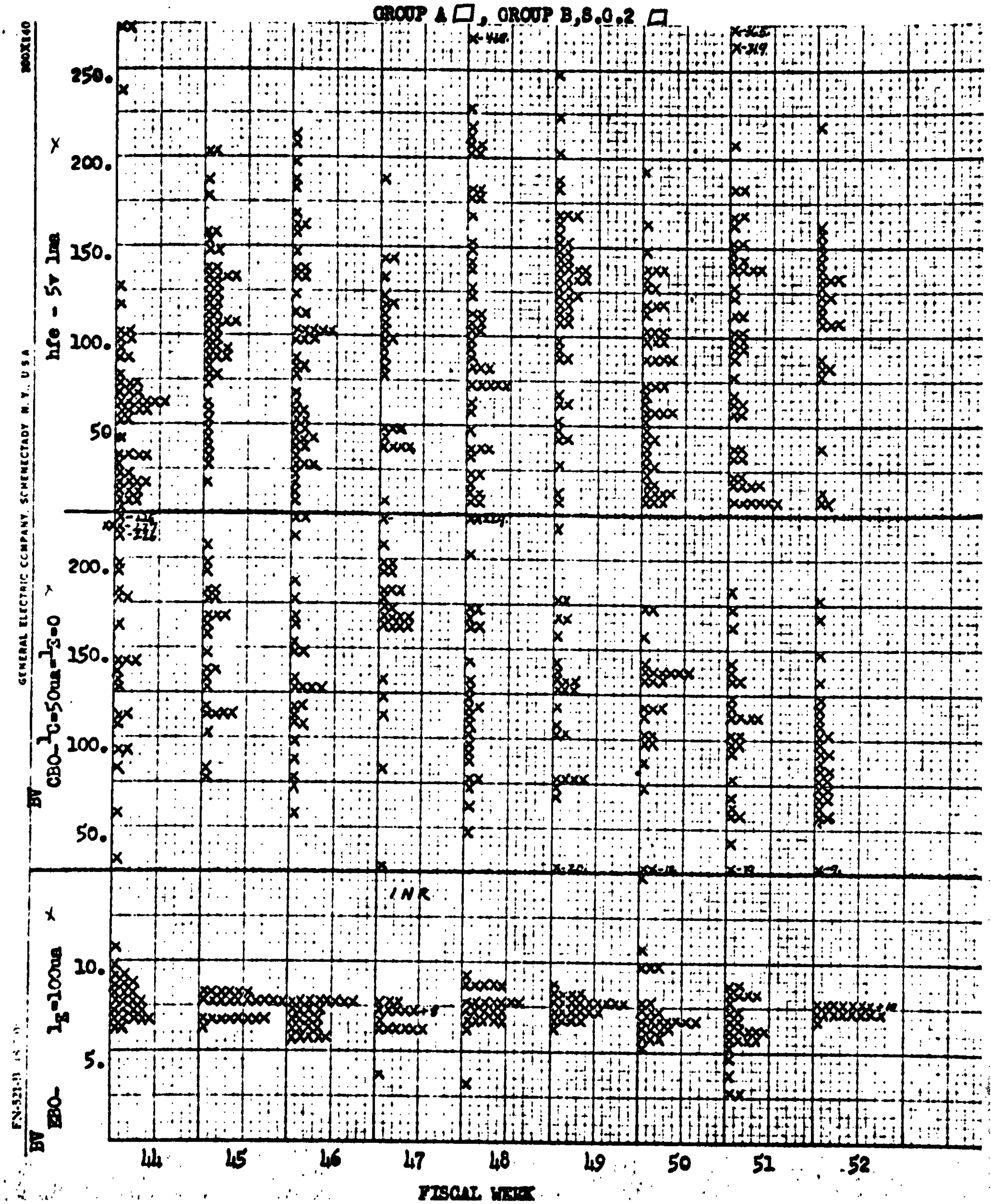
A Quality Control Report has been assimilated, describing the quality practices exercised by the General Electric Company in the construction of 2N336 transistors for the U. S. Army Electronics Materiel Agency. This report will be completed and sent to the Agency during the next quarter.

PARAMETER DISTRIBUTION BY WEEK

1962 - 4JD40 LINE, (2N332,2N333,2N335,2N336)

ELECTRICAL MEASUREMENTS PER MILT 19500/37A

GROUP A ☐, GROUP B,S.G.2 ☐

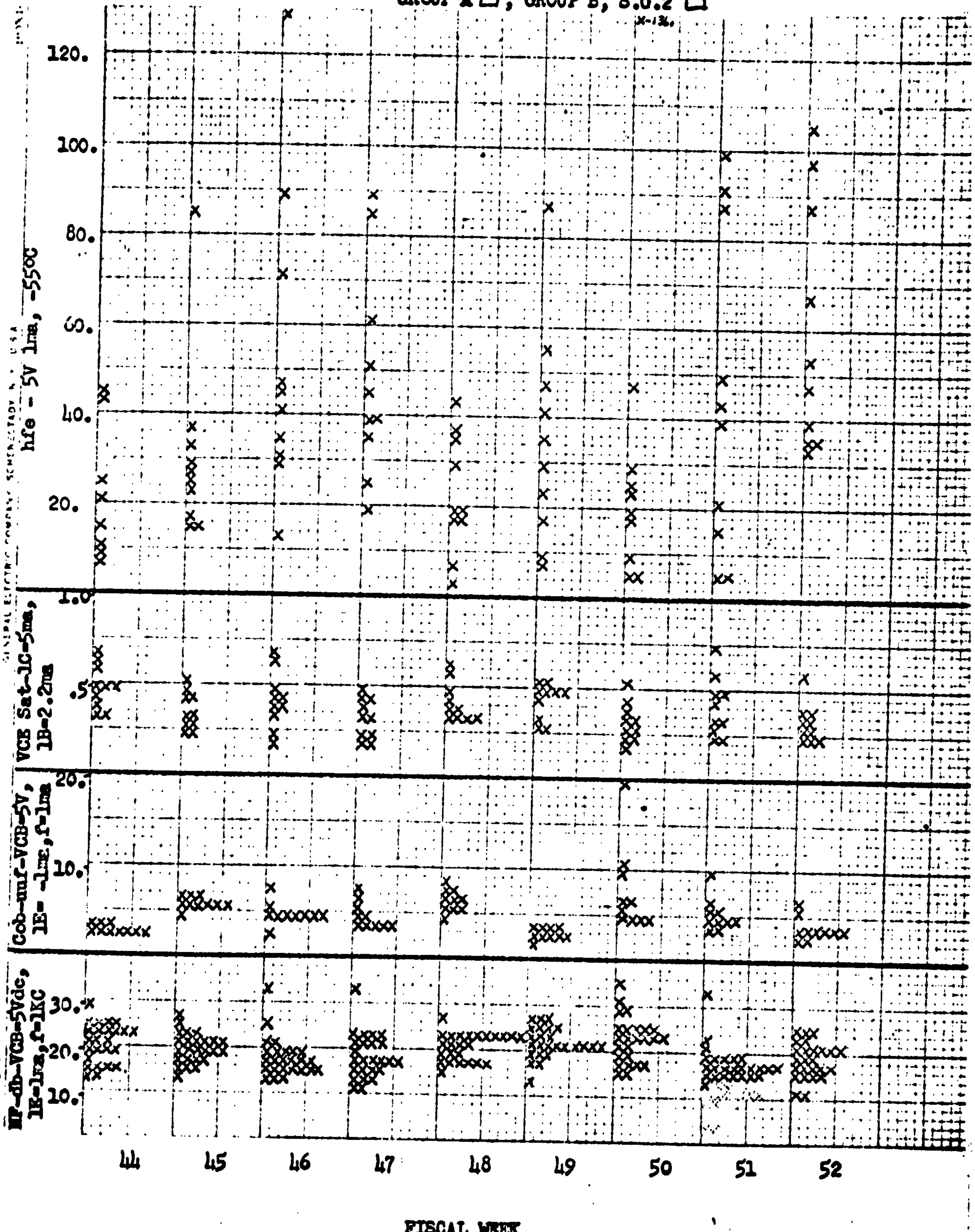


PARAM... DISTRIBUTION BY WEEK

1962 - 4JD4C LINE, (2N332,2N333,2N335,2N336)

ELECTRICAL MEASUREMENTS PER MILT 19500/37A

GROUP A ☐, GROUP B, S.O.2 ☐

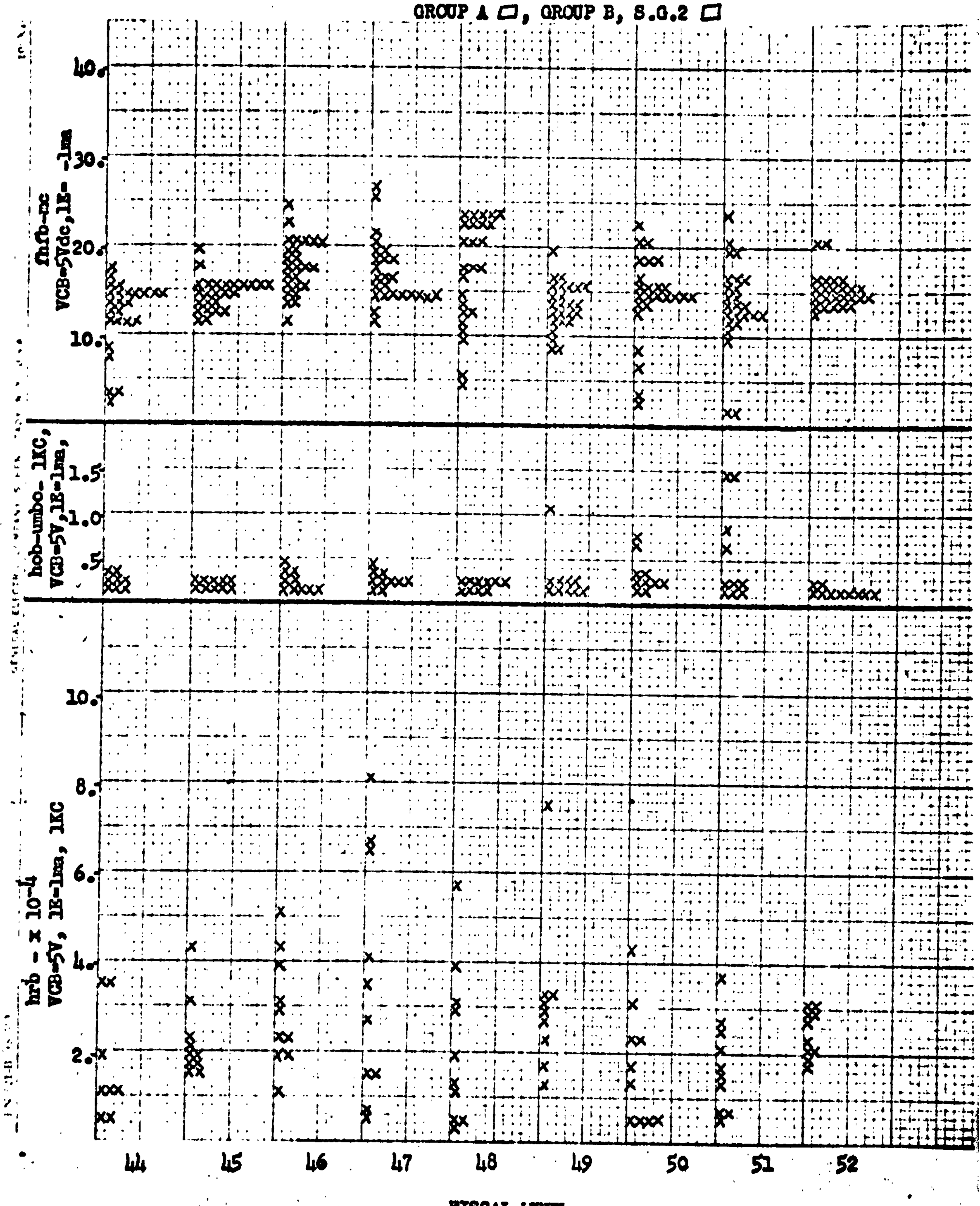


PARAMETER DISTRIBUTION BY WEEK

1962 - 4JD4C LINE, (2N332,2N333,2N335,2N336)

ELECTRICAL MEASUREMENTS PER MILT 19500/37A

GROUP A ☐, GROUP B, S.G.2 ☐

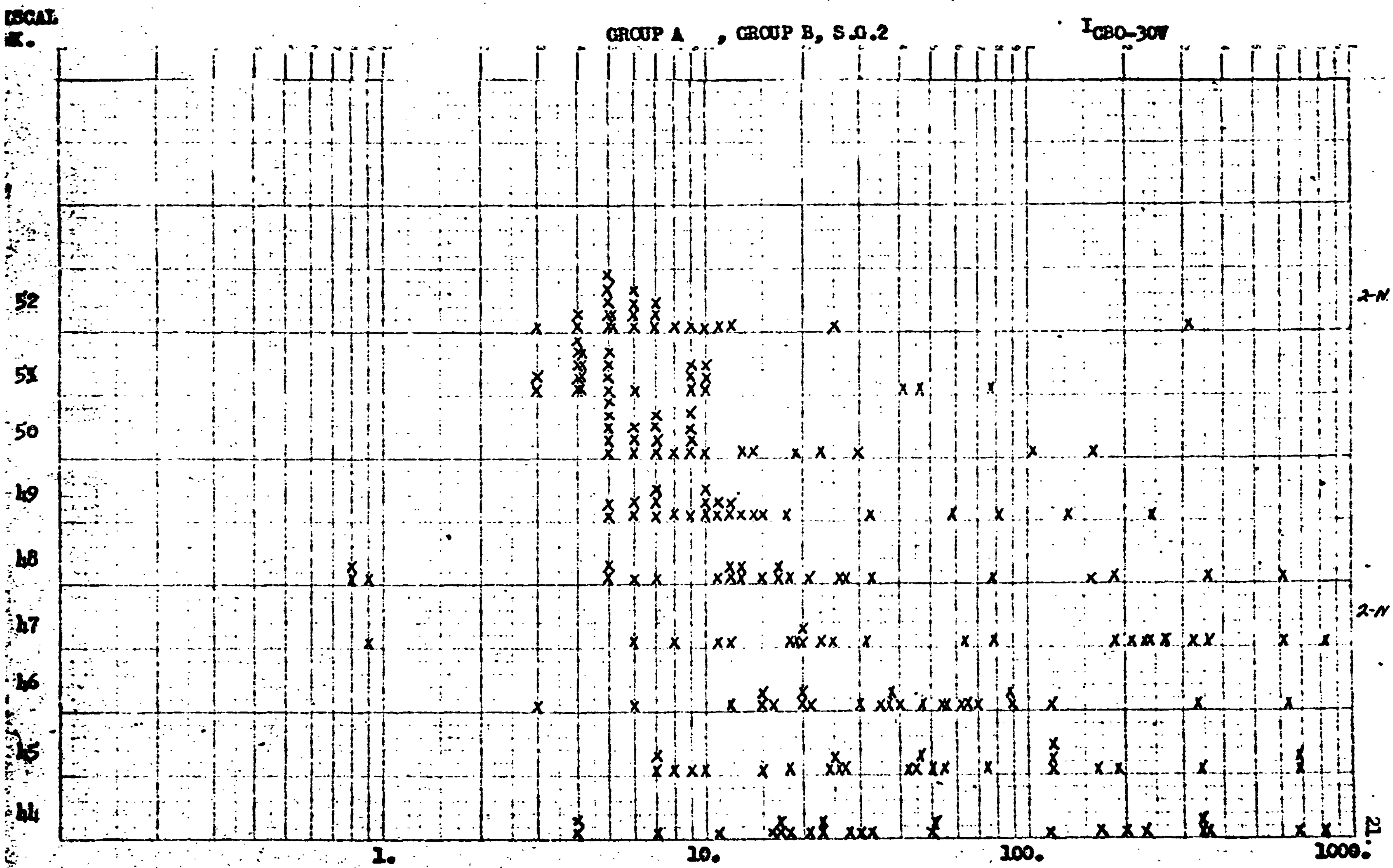


PARAMETER DISTRIBUTION BY WEEK

1962 - 4JD4C LINE, (2N332,2N333,2N335,2N336)

ELECTRICAL MEASUREMENTS PER MILT 19500/37A

GROUP A , GROUP B, S.Q.2



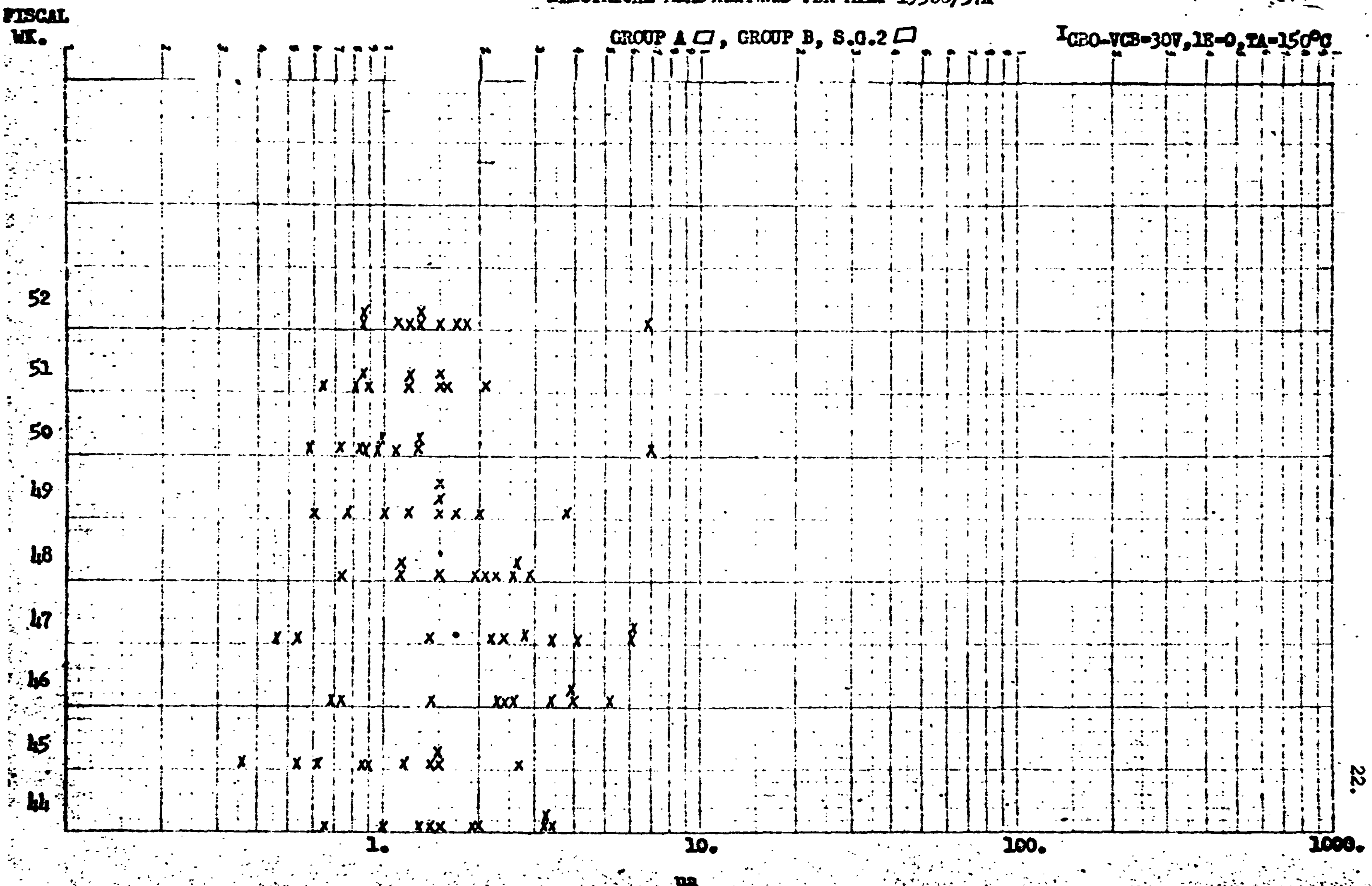
PARAMETER DISTRIBUTION BY WEEK

1962 - 4JDLC LINE, (2N332,2N333,2N335,2N336)

ELECTRICAL MEASUREMENTS PER MILT 19500/37A

GROUP A ☐, GROUP B, S.G.2 ☐

I_{CBO}-VCB=30V,IE=0,TA=150°C

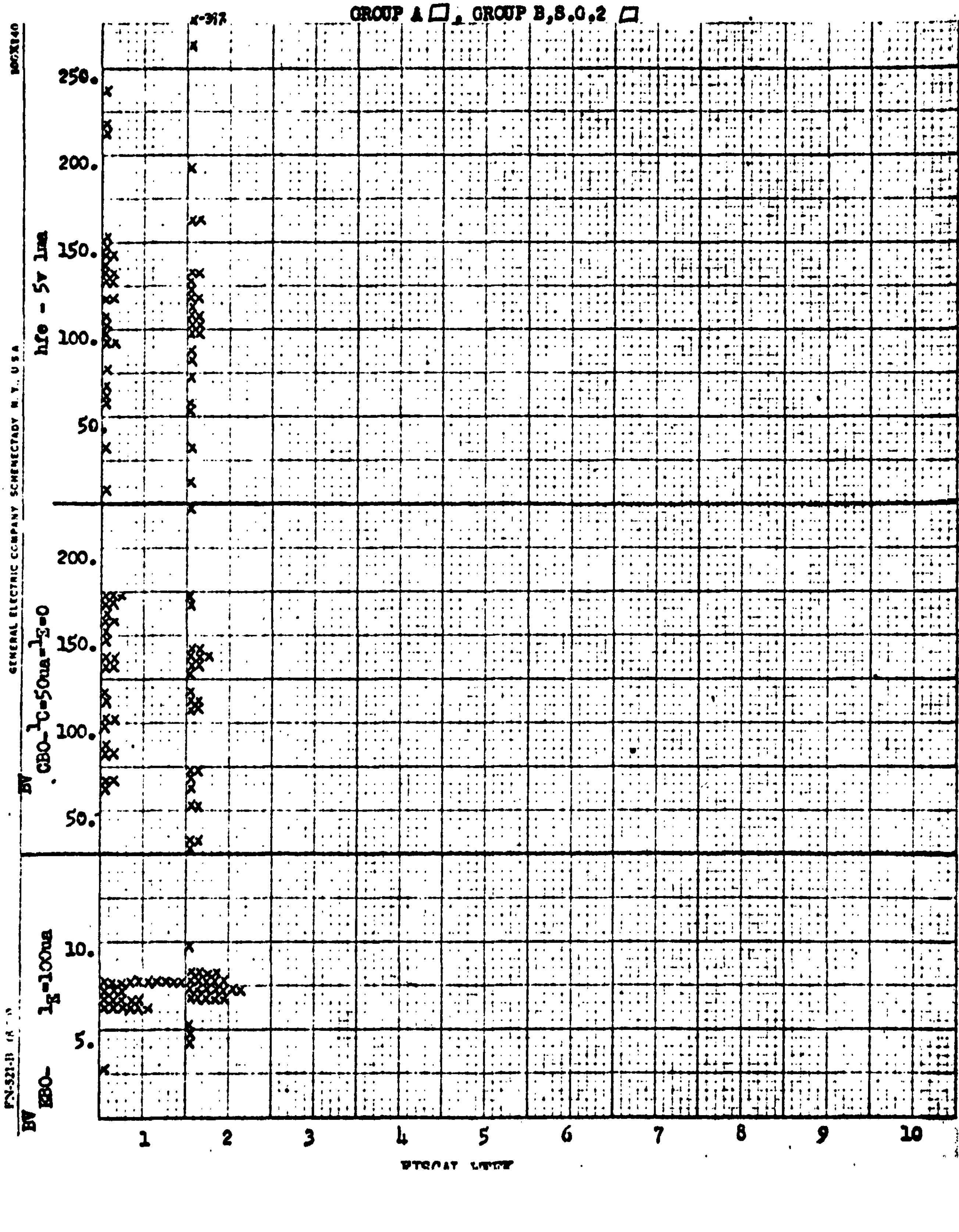


PARAMETER DISTRIBUTION BY WEEK

1963 - 4JD4C LINE, (2N332,2N333,2N335,2N336)

ELECTRICAL MEASUREMENTS PER MILT 19500/37A

GROUP A □, GROUP B,S,C,2 □

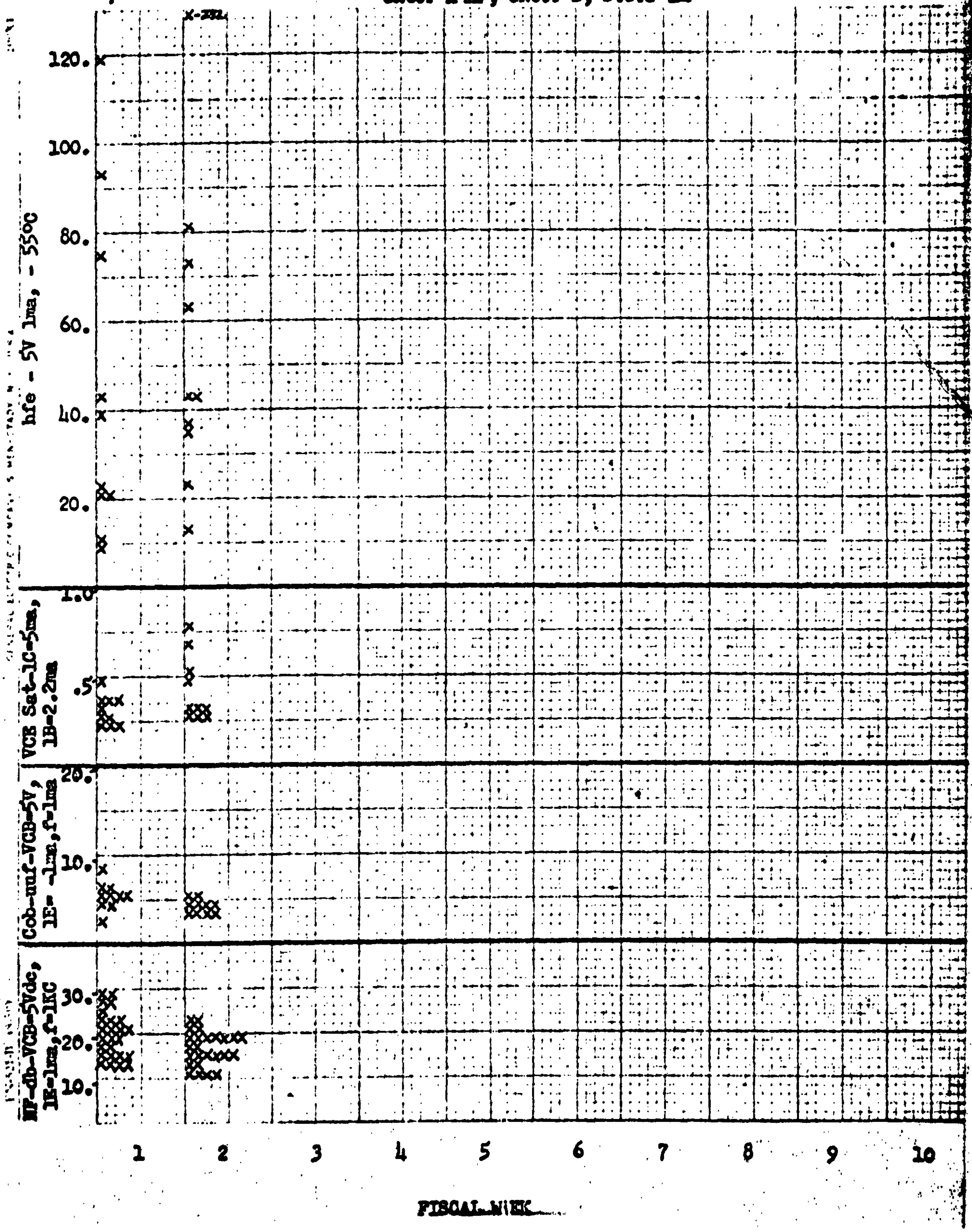


PARAMET… DISTRIBUTION BY WEEK

1963 - 4JD4C LINE, (2N332,2N333,2N335,2N336)

ELECTRICAL MEASUREMENTS PER MILT 19500/37A

GROUP A ☐, GROUP B, S.O.2 ☐

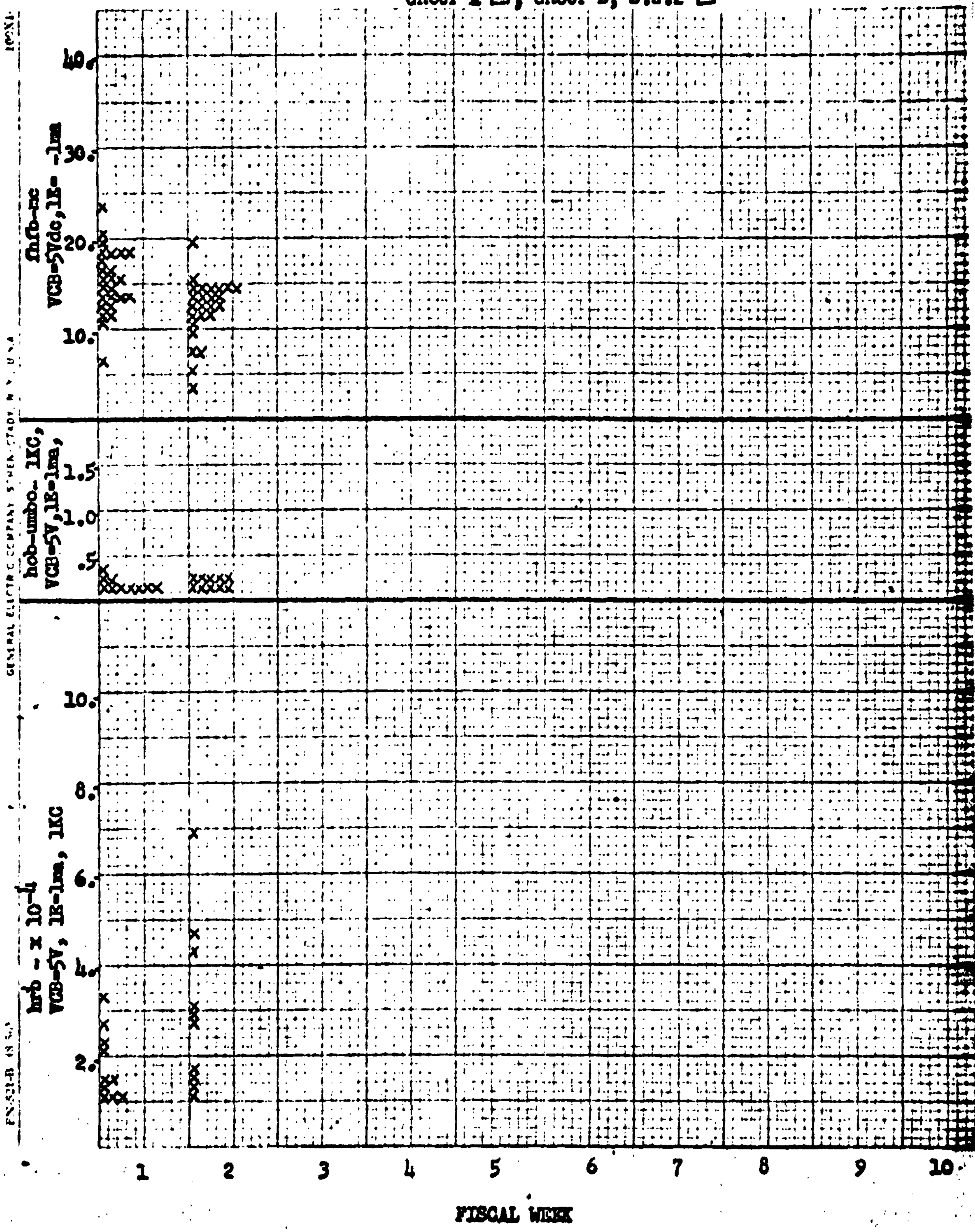


PARAMETER DISTRIBUTION BY WEEK

1963 - 4JD4C LINE, (2N332,2N333,2N335,2N336)

ELECTRICAL MEASUREMENTS PER MILT 19500/37A

GROUP A ☐, GROUP B, S.G.2 ☐

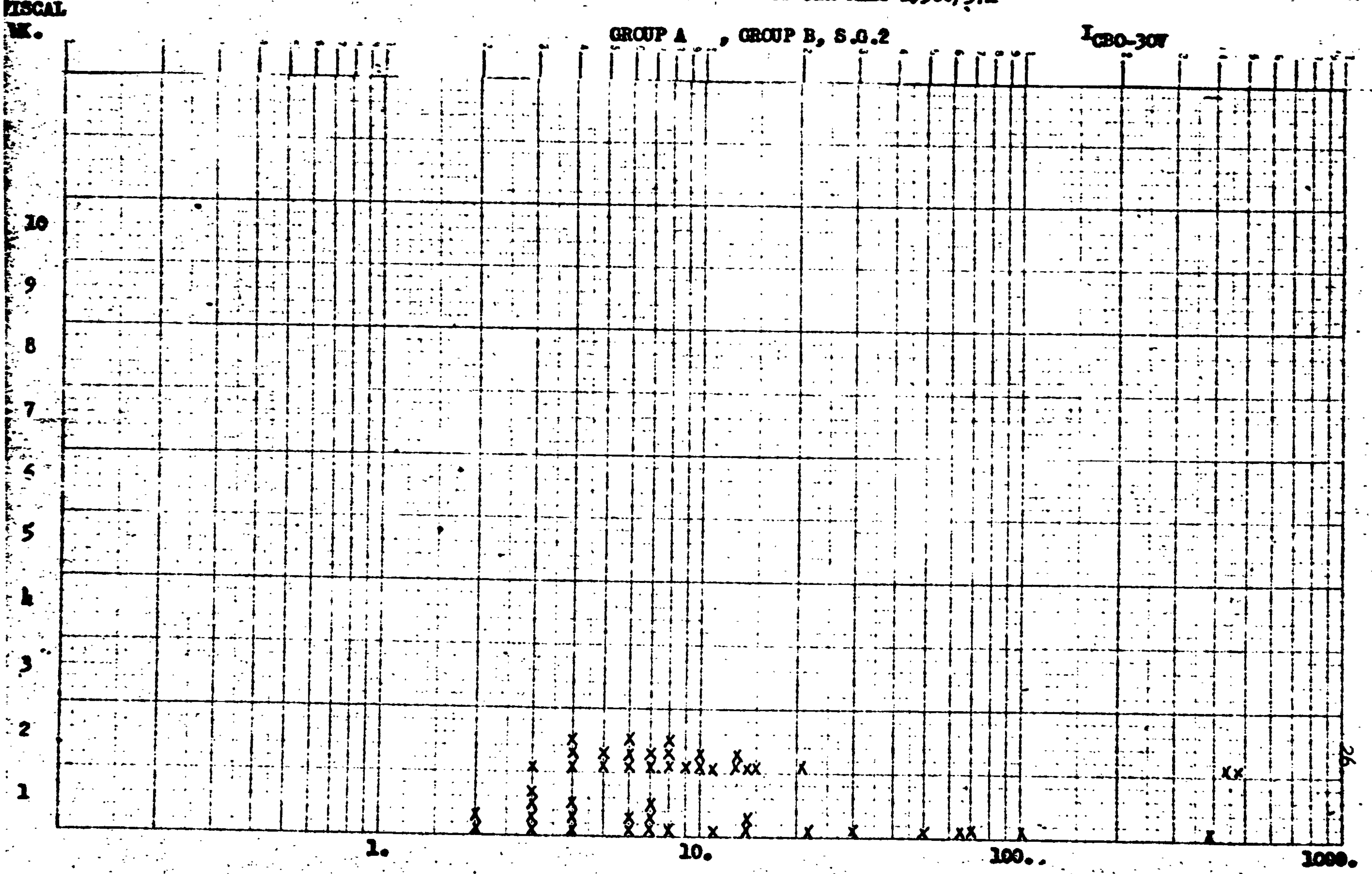


PARAMETER DISTRIBUTION BY WEEK

1963 - 4JD4C LINE, (2N332,2N333,2N335,2N336)

ELECTRICAL MEASUREMENTS PER MILT 19500/37A

GROUP A , GROUP B, S.G.2

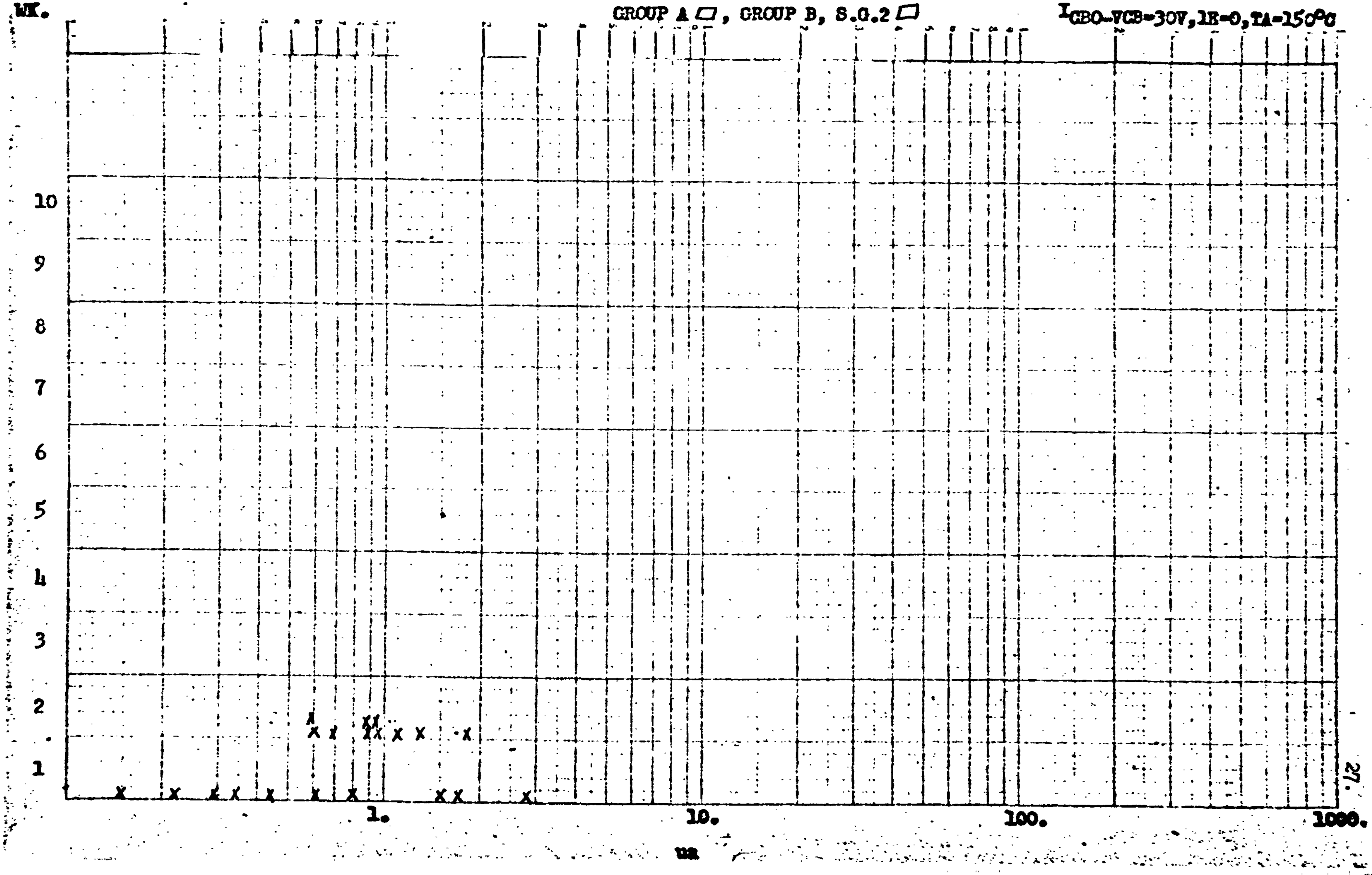


PARAMETER DISTRIBUTION BY WEEK

1963 - 4JDLC LINE, (2N332,2N333,2N335,2N336)

ELECTRICAL MEASUREMENTS PER MILT 19500/37A

GROUP A ▭, GROUP B, S.G.2 ▭



4. CONCLUSIONS

Reliability studies of the Automatic Passivation System to date show that there is no statistically significant difference between the new and the prototype systems. Nevertheless, the data seems to indicate that the automatic system is slightly the better, since the prototype units have experienced one failure in each of the accelerated life tests, and the I_{CBO} shift in the automatic system is slightly less. The temperature plus voltage screen appears to be an excellent method of removing potential I_{CBO} "up-shifters", especially on the power operating test.

The Main Seal welding machine is installed and ready for production evaluation. Cap loading escapement mechanisms are being investigated, but this will not interfere with the welding operation.

Increasing the flushing time and temperature during encapsulation has the net effect of increasing the positive delta beta shift on 200°C. storage. On the other hand, a high flush temperature and a short flush time yields the lowest I_{CBO} medians. Accordingly, the best compromise for flush temperature and time has been set at 250°C. and 24 seconds respectively.

5. PROGRAM FOR NEXT QUARTER

5.1 PASSIVATION

Data accumulation of devices will be completed.

5.2 HIGH TEMPERATURE MAIN SEALING

The twenty-head rotary welder will be placed in operation. Designs for an automatic cap loader will be explored and fabrication of the loader will begin when the better design is decided upon.

5.3 EXPERIMENTATION AND EVALUATION

The reliability experiment on the automatic passivation system will be completed. Experiments will be started to evaluate the effects of any significant process changes in life test results, if necessary.

5.4 CHARACTERISTIC DISTRIBUTIONS

The monitoring of the electrical parameter distribution of the 4JD4C line will continue. Parameters will be added as necessary, or dropped, if it is found that they can be controlled via correlation with other parameters.

The Quality Control Report for the 2N336 product will be sent to the U. S. Army Electronics Materiel Agency.

6. PUBLICATIONS AND REPORTS

6.1 Formal Quarterly Report

The Second Quarterly Report was completed, approved, and distributed.

PROFESSIONAL PERSONNEL

and

TOTAL APPLIED EFFORT

for period covering

31 October 1962 - 31 January 1963

PERSONNEL	MAN-HOURS
R. L. Lavallee	1,285
F. J. Potter	
P. W. Olski	
D. P. Smith	
T. E. Gates	
C. L. Jeffers	
R. R. Killian	
P. Marapodi	
W. A. Scherff	
A. Fox	

POTTER, FRANK J.

EDUCATION: Rensselaer Polytechnic Institute, BS(EE), 1949.
University of Arizona, Advanced Electronic Circuits.

PUBLISHED MATERIAL: "Measurement of Dynamic Characteristics of Semiconductors for Reliable Circuit Design". (Semiconductor Reliability, Vol. II. Also appeared in "Electronic Equipment Engineering", August and October, 1962.). Described a transistor analog at the Semiconductor Devices Conference, Purdue University, 1956.

PATENTS: Patent issued for diode test circuit for dynamic characteristics measurements.

EXPERIENCE:

1949 - 54:	General Agent, Insurance.
1954 - 56:	Motorola Semiconductor, Phoenix, Arizona - Application Engineer.
1956 - 61:	Stromberg-Carlson, Rochester, New York - Reliability and Evaluation Engineer.
1961 - 62:	General Electric Company, Semiconductor Products Department, Syracuse, New York. - Reliability and Special Evaluation Engineer, Germanium Low Frequency products.
1962 - :	Silicon Low Frequency products.

PROFESSIONAL SOCIETIES: Advisory member, AIA Semiconductor Devices Panel.
Advisory member of EIA M62 Committee.
Member of JS-8 Committee.
Alternate member of JS-9 Committee.
IRE professional groups on reliability and quality control, circuit theory and electron devices.